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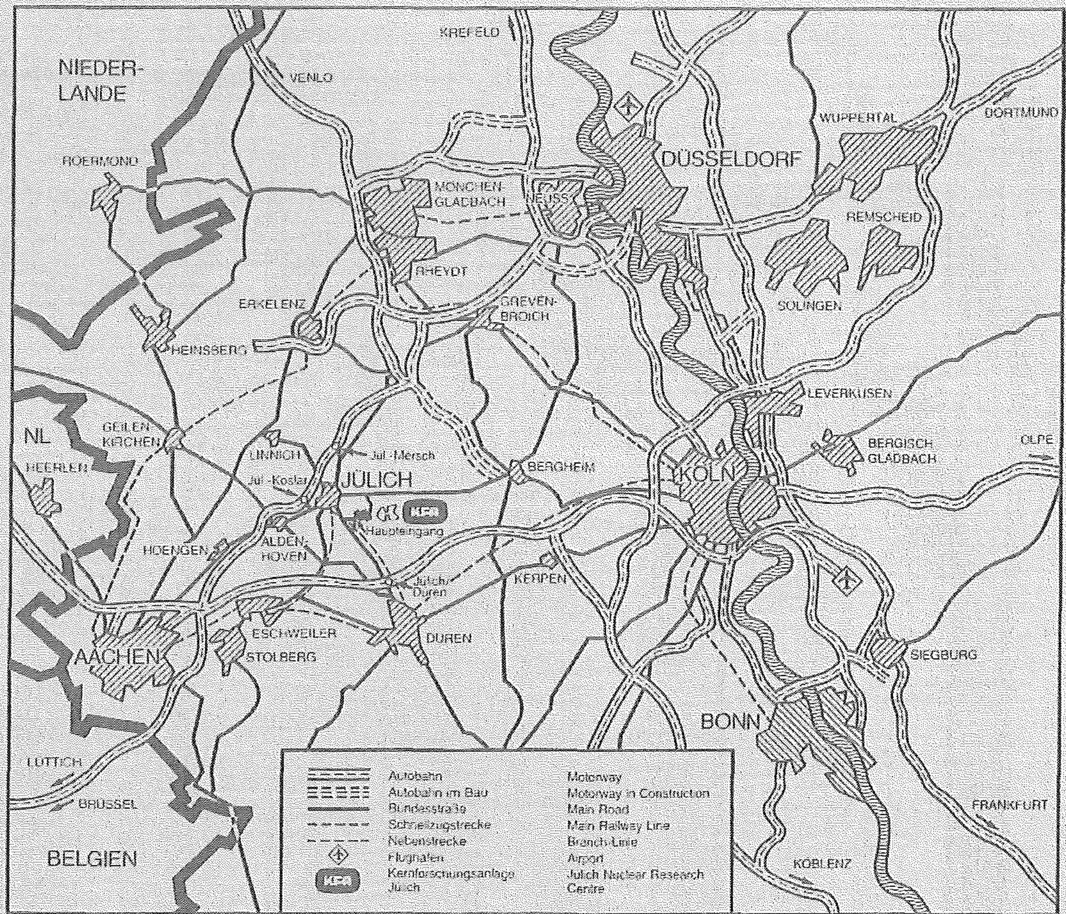


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# INTERNATIONAL SAFEGUARDS FOR A GEOLOGICAL REPOSITORY FOR THE FINAL DISPOSAL OF SPENT LIGHT-WATER POWER REACTOR FUEL

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Contribution to the R+D Programme
Alternative Waste Management Techniques
of the Federal Ministry
for Research and Technology

# SUMMARY

On the basis of the reference concept evolved within the framework of the research and development programme "Alternative Waste Management Techniques", safeguards concepts for a direct final repository are being compiled and evaluated. The safeguards under discussion begin with the arrival of the products for final disposal at the reception area of the geological repository and terminate with the measures envisaged for the post-operational phase of the repository. Safeguards for the conditioning facility or the transport of final disposal packages are not included in this study.

First of all in Chapter 2, important aspects of the reference concept have been selected and compiled for safeguards applications. The considerations are based on a standard PWR fuel element of the Biblis B type with a burn-up of 40,000 MWd/t HM at an initial enrichment of 3.6 %. After a cooling-down period of at least 10 years, the spent fuel elements are transferred in flasks of 12 fuel elements each to a conditioning facility which need not necessarily be at the site of the final repository. Conditioning is implemented in two sub-steps, preliminary conditioning and final conditioning. During preliminary conditioning three intact fuel elements are enclosed gas-tight in a so-called dry storage bin. The resulting intermediate storage package is brought into the final conditioning sector in a final disposal canister. A facility capacity of 700 t of heavy metal per year requires that 6 - 9 fuel elements be conditioned per day. 2 - 3 final disposal packages per day thus result in the final conditioning sector.

The geological repository is constructed in a virgin salt dome, the reference concept envisaging emplacement in tunnels with lost shielding. Access to the repository is obtained via two shafts. The first shaft serves to transport the salt, material and personnel. The second shaft is envisaged for

emplacement and special transports. Air inflow is effected via Shaft 1; exhaust air flows out through Shaft 2. Exploration of the envisaged emplacement area is implemented by exploratory drillings and tunnels. The exploratory tunnels roughly demarcate the emplacement area and are later to be used as ventilation galleries for exhaust air from the emplacement fields. After completing underground exploration, the position and size of the emplacement fields is determined. The emplacement floor will probably be 30 m below the exploratory floor at a depth of between 700 m and 900 m. Access to the emplacement area is obtained by driving two parallel access galleries joined by connection drifts at intervals of 200 m. Starting from the connection drifts, the emplacement galleries are driven parallel to the access galleries. Before beginning emplacement, emplacement galleries will only be driven starting from the emplacement connection drift furthest from the shaft. Emplacement galleries are driven from the next connection drift at the same time as emplacement is implemented in the first sector of the emplacement field.

The final disposal package is transported under ground on a rail-bound plateau transporter via Shaft 2. Underground transport to the emplacement connection drift is rail-bound; whereas transport through the emplacement connection drift to the emplacement gallery is railless. This is effected by an emplacement vehicle. After emplacing the package, the gallery section with the package is backfilled (mechanical or pneumatic stowing). When all the galleries of an emplacement sector are occupied by packages and filled-in the emplacement connection drift and ventilation galleries are also backfilled. After terminating emplacement operation - 40 weeks' operation per year, 11 FDP's per week - all the galleries and cavities are backfilled, in the same way as the shafts. It is intended to operate the mine for 50 years at an emplacement rate of 437 FDP's per year.

The NP aspects of a direct final repository are dealt with in Chapter 3. The accumulation of plutonium in a direct final repository is regarded as especially dubious with respect to non-proliferation ("plutonium mine"), since in principle later access by a nation to the very large quantities of plutonium can never be ruled out. Due to the large quantities of stored plutonium and the long operational period of such a repository, it must finally also be remembered that notice to or termination of the Non-Proliferation Treaty cannot be ruled out in various countries.

In this connection, the results and considerations of the INFCE Conference are of special importance. INFCE Group 7 WASTE MANAGEMENT AND DISPOSAL concerned themselves with the problems of safeguards in final repositories for spent fuel elements. INFCE considered it possible in principle to safeguard such a repository during the operational phase with safeguards techniques currently available. However, in the long term INFCE doubts the effectiveness of safeguards since the post-operational phase lasting for centuries will be determined by numerous unforeseeable technical, political and social factors.

In addition to the political and technical boundary conditions, three safeguards models are presented in Chapter 4 intended to ensure the safeguarding of a final repository. The models are differentiated by the degree of authorized access for IAEA inspectors. Thus in Model 1 access is restricted to aboveground facilities, Model 2 envisages limited access to the underground facilities and Model 3 unrestricted access to all underground facilities.

In Model 1 the inspector's access is limited to strategic points above ground. These strategic points are the key measurement points, the reloading facility above ground as well as the bank eyes of the mine shafts. The essential element of this model is that, after the material has been taken under ground, recovery or an internal diversion within the mine is ruled out. By transferring the material under ground, it is thus released from safeguards monitoring and written off. Since according to its definition there is no longer any material subject to safeguards present in this model after emplacement activities have been completed, neither is there any need for safeguards during the post-operational phase.

Before the material can be released from safeguards, proof of non-recoverability must be presented. If this cannot be presumed then routine inspections of the site will be required during the post-operational phase in order to monitor activities which could indicate a reopening of the mine or other measures for recovering the material.

The basic prerequisite for Model 1 is that the final repository itself can be regarded as a sufficient barrier so that measures can be dispensed with for ensuring that there is no undeclared containment opening through which the material could be recovered and that a diversion of material within a containment (reprocessing under ground) can be ruled out.

Model 2 comprises Model 1 and the following additional underground strategic points: pit bottom of both shafts, intersections of the access galleries with the emplacement connection drifts and the junctions of the emplacement galleries with the respective connection drift. These underground strategic points enable the inspector to safeguard the underground nuclear material flow at various stages of intensity. Largely the same restrictions as for Model 1 apply to this model. A termination of safeguards with backfilling of the gallery would have to be possible, or the geological repository itself would have to be regarded as a sufficiently safe barrier. The access of inspectors to strategic underground points would indeed present a serious obstruction to a diversion in the geological repository, but it cannot be ruled out with sufficient certainty.

Model 3 comprises Model 2 and moreover as an additionl measure the access of inspectors to all underground facilities and installations. Measures for containment and/or surveillance are thus suggested in all the aboveground and underground facilities and installations of the final repository, including the waste storage area.

Based upon these three safeguards models, a diversion and abuse analysis has been compiled as well as an evaluation of effectiveness leading to the following results: sufficient safeguards can be ensured both in the phase of aboveground transport (Phase 1) as well as in the phase of transporting the final disposal package under ground until it is filled-in on site (Phase 2). During the operational phase safeguards on final disposal packages already backfilled (Phase 3) can consist of permanent design reverification (Safeguards Model 3); however, unsolved problems can be seen in evaluating their effectiveness. The same is true of verifying the integrity of the shut-down geological repository in the post-operational phase (Phase 4).

In Chapter 5 approaches are suggested and discussed for solving the safeguards problem. An initial approach is perceived in altering the existing IAEA safeguards philosophy. The IAEA considers it necessary to quantify objective variables by compiling numerical detection objectives (significant quantity, detection time, probability of detection, probability of false alarms). The probability of detection is the essential variable in the IAEA safeguards towards which the planning of safeguards, employment of resources and evaluation of effectiveness are oriented. Since there is currently no procedure for quantifying the probability of detection in applying containment and surveillance measures, safeguards models which are largely or, as required in the case of the final repository, almost exclusively based on C/S measures, cannot be objectively planned in this model nor is their effectiveness computable. This leads to them being classified as unacceptable by the IAEA.

A second approach is seen in the further development, and possibly redevelopment, of safeguards elements. In the operational phase of the final repository the problem consists in communicating a quantifiable certainty to the safeguards authority by suitable measures that the emplaced material is still present. Strictly speaking this quantification is only possible for accountancy measures. No methodology has yet been developed for numerically determining the information content of C/S measures; the error associated with C/S verification cannot be precisely specified. This problem can generally be mitigated in other facilities by implementing material verification in principle by accountancy measures and by only employing C/S measures for subsidiary quantities of material and for limited periods as a supportive measure. These restrictions (limitation to subsidiary quantities and defined periods) must be dispensed with in the case of the final repository. Safeguards would thus only be possible with purely a C/S concept and there is no contractual nor methodological basis for this. I.e., even presuming that safeguards elements were to be redeveloped or further developed, thus enabling C/S-supported monitoring of the emplaced material, its inclusion in the safeguards system would only be possible as a supplementary measure. On their own they do not represent a basic solution to the problem under consideration.

Adaptation of the reference concept to the currently valid safeguards practice is discussed as the third approach. The starting points for this discussion are conditioning the material in such a way (dissolution and dilution) that the termination criteria for safeguards monitoring are fulfilled, or emplacing the material in such a way (recoverable) that it remains accessible for verification measures. Both methods of treatment are unacceptable as realistic alternatives. By dissolving the fuel and conditioning in the form of PAMELA ingots the capacity e.g. of the Gorleben salt dome would not even be sufficient for a single annual throughput of 700 t of nuclear fuel. By emplacement in such a way that the material would remain accessible for further verification, apart from the technical feasibility, the essential objectives of the final repository concept would not be fulfilled, namely isolating the material from the biosphere and from possible further human access. Accessible underground emplacement would probably raise so many problems for reasons of heat removal and rock stability that this could no longer be regarded as a modification to the reference concept but would rather require compiling a new concept.

As a fourth approach, possibilities for solutions in the institutional sector are discussed. The starting point for institutional approaches is the fact that in order to implement a diversion a considerable amount of organizational work must also be undertaken in addition to the necessary technical measures. By forms of multinational cooperation, additional barriers could be erected in the organizational sector which would make a diversion more difficult and would increase the risk of detection. A further aspect is that by extending international involvements, the states would probably be more vulnerable to sanctions.

Consideration of institutional aspects received essential impulses through the INFCE Conference and is reflected in the IPS Working Group. It must, however, be remembered that institutional aspects are regarded by the IAEA as supplementary measures and not as an alternative to stringent technical monitoring. Institutional models with multinational codetermination or cooperation undoubtedly represent an approach to general NP problems of a final repository due to the associated proliferation barrier. However, they are not appropriate for solving the safeguards problem. In this connection the special role of EURATOM will be discussed, which has proprietary rights to nuclear material and special rights in the storage of nuclear material on the basis of contractual boundary conditions.

An evaluation of the approaches mentioned above is undertaken in Chapter 6. The first approach to the safeguards problems of a final repository was seen in modifying the existing IAEA safeguards philosophy. According to this the IAEA would have to accept a safeguards model based largely - or in the post-operational phase exclusively - on C/S measures. Since in this case the probability of detection, i.e. the essential objective of IAEA safeguards, cannot be quantified at the present state of the art, such an approach would be regarded as unacceptable by the IAEA. It is not possible to verify the nuclear material in the case of anomalies, e.g. false alarms.

For the same reasons the second approach, envisaging the further technical development of safeguards elements, cannot be presented as a basic solution to these inherent safeguards problems either.

The third approach consists in ensuring the safeguardability of the final repository according to current safeguards practice by altering the reference concept (e.g. by dissolving and diluting the nuclear fuel). No realistic possibilities are in sight in this case either, since doubt is thus cast on many of the desired characteristics of a direct final repository.

Institutional models with multinational participation and co-operation (fourth approach) undoubtedly represent a simplification of the NP problems of the final repository due to the associated proliferation barriers. But in addition to the resulting problems of political acceptance they are not suitable for solving the safeguards problem either. In this context the role of EURATOM, resulting from its safeguards functions and its proprietary rights to all special fissionable materials, must be taken into particular consideration in establishing a direct final repository.

Before a concluding resolution, it will be of interest to compare the essential NP aspects of direct final emplacement with reprocessing. This comparison clearly reveals the advantages of a waste disposal strategy with reprocessing.

On the basis of the facts and analyses compiled, the conclusion becomes apparent that the waste management strategy with a direct final repository is problematic from safeguards aspects since doubt is cast on the technical realization of a safeguards concept.

For certain types of fuel element where reprocessing is not envisaged and not worthwhile, Art. 35 VA can offer a possibility of a solution. In this case of the limited emplacement of spent fuel elements it could be possible to negotiate international safeguards according to this Article.

CONTENTS

Page

# 1 INTRODUCTION

The possibility of the direct final disposal of spent fuel elements is considered as an alternative to the commercial reprocessing of fuel elements. Final disposal aims at isolating radioactive material from the biosphere and from possibilities of accidental human access without any time limit. The safety concept is designed to ensure the integrity of the repository without requiring human maintenance or monitoring after the final closure of the repository. Final disposal is conceived of as irreversible disposal.

Within the framework of the research and development programme "Alternative Waste Management Techniques" the emplacement of spent fuel elements in a salt dome is being studied. Several concepts have been compiled for conditioning, for the final disposal canister and emplacement techniques for this direct final disposal of spent fuel elements. One concept which best fulfills the criteria of safety engineering, technical feasibility, availability of raw materials, and also approaches to economic efficiency and nuclear materials safeguards, was selected as a reference in each case. Back-up solutions for each component were also determined over and above establishing the reference concepts.

A nuclear materials safeguards concept is to be developed by the KFA-TUG on the basis of the reference concept. This safeguards concept for Alternative Waste Management comprises safeguarding the products for final disposal from their arrival at the geological repository. Individual aspects important for applying international safeguards measures have been selected and compiled in Chap. 2 from the large volume of information required for this concept and from detailed technical problems already known.

The reference concept is based on a pressurized water reactor standard fuel element of the Biblis B type with a burn-up of 40,000 MWd/tHM at an initial enrichment of 3.6 %.

After a cooling-down period of at least 10 years the spent fuel elements are transported in flasks of 12 fuel elements each to a conditioning facility. Conditioning is effected in two steps, preliminary conditioning and final conditioning. In order to ensure that its capacity is continuously exploited the facility has a reception store for approx. 20 flasks.

The spent fuel elements are enclosed in a final disposal package (FDP) in the conditioning plant. An FDP consists of three containers: the dry storage bin (DSB) as a gas-tight barrier, the final disposal canister (FDC) primarily designed according to the criteria of corrosion protection and stability, and the lost shielding (LS) which serves as a protection against neutron and gamma radiation during handling and transport.

The finished FDP's are transported from the conditioning facility to the geological repository in special flasks on special freight cars owned by the Deutsche Bundesbahn (Federal German Railways). The FDP's are taken out of flasks and individually loaded onto plateau transporters at the reloading plant of the geological repository for transport under ground. A reception buffer store serves to accommodate FDP's in the case of disturbances in emplacement operation. During normal operation the FDP's delivered are taken directly under ground and there emplaced according to regulations.

With respect to nuclear materials safeguards, no experience is yet available for direct final disposal. From the point of view of proliferation, a final repository for spent fuel elements containing strategic material represents an increasingly attractive object for a potential diverter and thus requires effective safeguards for which new techniques and concepts must be developed due to the special problems involved.

Safeguards instrumentation currently available is based on material accountancy and independent material verification which in the case of a final repository with the purpose of isolating material from the biosphere and preventing further possibilities of access can no longer be directly applied.

In the following the direct final emplacement of spent fuel elements, an interesting possibility also for other states, is therefore investigated from safeguards aspects with respect to the Féderal Republic of Germany which, in contrast to other signatory states of the NP Treaty, does not have a national safeguards system. Whether and to what extent available safeguards elements can be combined into an effective safeguards concept is analyzed under the boundary conditions given for the final repository, or which modifications may possibly be necessary.

# 2 TECHNICAL REFERENCE CONCEPT WITH SPECIAL REGARD TO SAFEGUARDS

## 2.1 Conditioning the Products for Final Disposal

### 2.1.1 Preliminary Conditioning

In the preliminary conditioning functional area 3 intact fuel elements are each enclosed gas-tight in a so-called dry storage bin (DSB). The individual process steps are distributed between 3 separate cells connected to each other by a DSB transport vehicle coupled to the cell openings in a ventilatively tight manner. The preconditioning sequence proceeds as follows:

The flasks taken from the reception buffer store are docked onto the opening in the floor of the fuel element unloading cell. After removing the fuel elements (FE), they are examined and deposited in the FE buffer store.

After docking the DSB onto the opening in the floor of the fuel element buffer cell, the lid of the opening is opened and the fuel elements placed in the DSB. The fuel elements are transported suspended on a cell crane when removing them from the fuel element buffer store. The trap door in the bin-loading cell is then closed again and the loaded DSB proceeds to the next cell, the welding cell.

In the welding cell the screw cap is inserted in the DSB and welded on. Helium is then fed in for the subsequent leak test and the filling hole is closed by welding.

The transport vehicle then proceeds to the opening in the floor of the testing cell and is coupled to the cell opening. In the testing cell the dry storage bin is taken over by the cell crane. The DSB transport vehicle is uncoupled and proceeds to the material transfer room where it is loaded with an empty dry storage bin. The welded DSB is taken to the decontamination device in the testing cell and after a wipe test is decontaminated if necessary. The DSB is subsequently subjected to an integral helium leak test in a pressure container and then after passing the test is transferred out of the cell and placed in a buffer store.

The dry storage bin used during preliminary conditioning can accommodate three intact fuel elements. It consists of a tube, bottom, cap and internals. On the lid there is a device for suspending it from a crane. The tube length of the DSB is 5.14 m, the tube diameter is 66.5 cm and the walls are 8 mm thick.

As a parallel approach to the preliminary conditioning described above, the method of "Fuel Elements Separated Into Fuel Rods" is currently being investigated. This will not be discussed in detail here since those components of the final disposal package relevant to safeguards in the final repository are practically unaltered by this alternative method of treatment.

### 2.1.2 Final Conditioning

The process steps in final conditioning begin by taking over the dry storage package (DSP), that is to say the loaded DSB, from the buffer store in preliminary conditioning and are terminated by passing on the final disposal package. In order to take over the DSB, an empty FDC is driven on a railway truck under the outward transfer room of the preliminary conditioning. The dry storage package coming from the buffer store is placed in the final disposal canister by the crane. The railway truck then transports the loaded FDC under the inward transfer room of final conditioning.

The final disposal canister is first raised here by means of lifting tackle on the railway truck and the lid is placed in position by the cell crane and then screwed on. The crane then picks up the FDC and deposits it at the welding facility. Automatic welding equipment applies the seal weld of the second lid at several positions. The weld seam is then visually inspected and a helium leak test then follows for liquid-tightness.

The tested final disposal canister is then inserted in the lost shielding by the cell crane located in the output transfer room. The lost shielding is closed by means of a screw cap. The final disposal package in a Type B flask then proceeds to the geological repository on a special Federal Railways truck.

The final disposal canister is intended to ensure the safe containment of the radioactive material for a period of about 500 years. Due to the geometry of the intact fuel elements, a maximum length for the final disposal package of 6.2 m would seem to be appropriate. This weighs approx. 50 t, it is designed for a heat output of 2.4 kW.

Nine fuel elements must be conditioned per day in order to achieve an annual capacity of 700 t heavy metal; the preliminary conditioning functional area is therefore designed in two legs. 2 - 3 final disposal packages therefore reach the final conditioning functional area per day.

## 2.2 The Geological Repository

### 2.2.1 Specifications

The geological repository will be constructed in a virgin salt dome. The reference concept envisages emplacing FDP's with lost shielding in tunnels. The emplacement level is to be at a depth of approx. 730 m. The repository is to be operated for 50 years at an emplacement rate of 437 final disposal packages per year. With 40 operating weeks per year two final disposal packages must be emplaced on four days of the week and three final disposal packages on one day, i.e. 11 final disposal packages per week. Only one emplacement level is envisaged. A maximum temperature of 200°C is presumed for the salt in the emplacement area, as in the HAW concept. It is hoped to achieve a temperature of 150°C at the salt-canister interface. Before beginning emplacement the rock temperature at a depth of 730 m is approx. 37°C.

| | |
|---|---|
| Number of Shafts . . . . . . . . . . . . . . . . . . . . . | 2 |
| Internal Diameter of the Shafts . . . . . . . . . . . . . | 7.50 m |
| Shaft Intervals . . . . . . . . . . . . . . . . . . . . . . . | approx. 400 m |
| Working Load Shaft I . . . . . . . . . . . . . . . . . . . | 25 t |
| Working Load Shaft II . . . . . . . . . . . . . . . . . . . | approx. 60 t |

**Table 2-1: Shaft Data**

The shaft transport equipment for emplacement operation is to be designed for a working load of approx. 60 t. At the same time as emplacing fuel element packages from fuel conditioning, secondary waste is emplaced via the same shaft but in a separate emplacement field.

| | |
|---|---|
| Operational Life . . . . . . . . . . . . . . . . . . . . . . . . . . . . | 50 a |
| Depth of the Emplacement Level . . . . . . . . . . . . . . . . . | approx. 730 m |
| Emplacement Rate for FE Packages . . . . . . . . . . . . . . . | 2 or 3 per day |
| Admissible Temperature of the Salt in the Emplacement Area . . . . . . . . . . . . . . . . . . . . . . . . . | max. 200°C |
| Temperature at the Salt-Canister Interface . . . . . . . . . . | approx. 150°C |
| Rock Temperature Before Beginning Emplacement . . . . . | 37°C |
| Working Load of the Shaft Transport Equipment for Emplacement Operation . . . . . . . . . . . . . . . . . . . . . | approx. 60 t |
| Products for Final Disposal . . . . . . . . . . . . . . . . . . . | Spent LWR-FE's, waste from the conditioning facility, nuclear power stations, regional collecting depots, research establishments etc. |
| Cross Section of the Tunnels in the Emplacement Floor . . . | approx. 22 $m^2$ |

**Table 2-2: Specifications for the Geological Repository**

| | |
|---|---|
| Cross Section of the Exploratory Tunnels . . . . . . . . . | approx. 15 $m^2$ (without vaulting) |
| Connection Drift Intervals . . . . . . . . . . . . . . . . . . | 200 m |
| Distance of the Emplacement Floor from the Exploratory Floor . . . . . . . . . . . . . . | 30 m |
| Access Gallery Intervals . . . . . . . . . . . . . . . . . . . | 500 m - 1800 m |
| Dimensions of the Emplacement Fields . . . . . . . . . . | 500 x 200 $m^2$ to 1800 x 200 $m^2$ |
| Cross Section of the Access Galleries and Connection Drifts . . . . . . . . . . . . . . . . . . . . | 7 x 4 $m^2$ |
| Cross Section of the Emplacement Tunnels . . . . . . . | 5 x 4 $m^2$ |
| Thickness of the Pillars from the End of the Emplacement Gallery to the Next Connection Drift . . . . | 7 m |
| Ascending Gradient of the Connection Galleries . . . . . | 10 - 12 % |

**Table 2-3: Data on the Position and Dimensions of Tunnels and Fields**

### 2.2.2 Developing the Geological Repository

A final evaluation on the suitability of the salt dome requires underground exploration by mining development. This mining development will not be conventional, i.e. largely without blasting. Access to the repository will be obtained via two shafts each 7.5 m in diameter at a distance of approx.

400 m. The first shaft serves for removing salt, transporting the material, man-riding and the incoming air. The working load of the transport facility is approx. 25 t. The second shaft, where the transport facility has a working load of approx. 60 t, serves for emplacement transport and the exhaust air.

Exploration in the envisaged emplacement area is undertaken by exploratory drillings and tunnels. The exploratory tunnels will have a cross section of 5 x 3 $m^2$ without vaulting. They roughly delineate (deviation of up to 25 m) the emplacement field and will later be used as ventilation galleries for the exhaust air from the emplacement fields.

The underground infrastructure area will be constructed between the two shafts. This includes the pit bottom, hopper, crushing and dust-removing facilities, as well as workshops for the assembly and maintenance of the machines, facilities and motor vehicles used under ground. The planned dimensions of the mechanical workshop are given in Table 2-4. The workshop is equipped with lifting platforms. A travelling crane with a load of 25 t is envisaged.

| Dimensions of the Workshop | |
|---|---|
| Length | 85 m |
| Width | 15 m |
| Height | 6 - 8 m |
| Load of the Travelling Crane in the Workshop | max. 25 t |

**Table 2-4: Data on the Workshop**

The position of the emplacement fields will be determined after completing underground exploration. The emplacement floor will be 30 m below the exploratory floor.

Access to the emplacement area will be obtained by driving two parallel access galleries up to the boundaries of the field. The access galleries are joined by connection drifts at intervals of 200 m. The emplacement galleries are driven parallel to the access galleries starting from the connection drifts. The emplacement tunnels are not driven right through so that a pillar of 7 m remains between the end of the tunnel and the next connection drift. The access galleries and connection drifts have a cross section of 25 $m^2$, the emplacement tunnels 18 $m^2$. The distance between the two access galleries depends on geological conditions in the salt dome and may be between 500 m and 1800 m. The individual emplacement fields correspondingly have dimensions of 500 m x 200 m to 1800 m x 200 m. In the final disposal package emplacement field, 18 connection drifts with 50 emplacement tunnels each and 1 connection drift with 40 emplacement tunnels are planned. Only the emplacement tunnels of the connection drift furthest from the shaft will be driven before beginning emplacement. The emplacement tunnels in the next emplacement connection drift are driven at the same time as emplacement is effected in the adjacent emplacement connection drift.

The emplacement floor is connected to the infrastructure area on the exploratory floor in the form of sloping tunnels as belt and chute raises with an ascending gradient of 10 - 12 %.

### 2.2.3 Emplacement Operation

Emplacement is effected by retreating working, i.e. from the most remote boundaries of the underground excavations towards the shafts. Before beginning emplacement, all emplacement tunnels are first driven in the field furthest from the shaft. A pillar of 15 m remains between the first emplacement tunnel and the access gallery. The width of the pillars between the emplacement tunnels is 10 m. After the first emplacement connection drift has been completely driven, emplacement operation will begin in it. Tunnelling the second connection drift proceeds parallel to emplacement.

The final disposal package is transported below ground on a rail-bound plateau transporter via the shaft envisaged for emplacement operation (cf. the sequence diagram in Fig. 2-1). The plateau transporter does not have any driving mechanism of its own and no brakes, and has to be propelled by a locomotive. The technical specifications are given in Table 2-5.

| Plateau Transporter | |
|---|---|
| Length | approx. 6.0 m |
| Width | approx. 2.5 m |
| Weight | approx. 8 t |
| Axle Load | approx. 35 t |
| Track Gauge | 1.435 m (Federal Railway gauge) |

**Table 2-5: Plateau Transporter Data**

The plateau transporter with the final disposal package is driven into the hoisting cage of the shaft winding equipment, is secured and transported through the shaft to the emplacement floor. A locomotive then takes over the transportation and drives the plateau transporter on rails along the access gallery solely designed for package transport to the emplacement connection drift. The gauge also corresponds to Federal Railway standards. Still on the access gallery, the emplacement machine takes over the package from the plateau transporter at the intersection of the connection drift and tunnel, and transports it without rails through the emplacement connection drift to the emplacement tunnel. After placing the package at the location of emplacement, the emplacement machine returns to the access gallery where the plateau transporter has in the meantime been driven back to the shaft and then taken to the surface. The section of the tunnel with the FDP is then filled in with crushed salt for a distance of 7.5 m. Mechanical or pneumatic stowing is used as the filling process. The filling vehicle is a railless vehicle with sliding sides on which a mechanical stowing machine is mounted. The emplacement sequence is shown in Fig. 2-1.

The stowing material is fed to the stowing machine via a conveyor system from the advanced working or a hopper. Aggregates in the form of MgO concrete can be added. The stowing machine drives to the emplacement location and mechanically fills the section of the tunnel to be closed. This method achieves a 98 % degree tunnel filling.

The distance between adjacent emplacement connection drifts is 200 m. Since 7 m remains as the end pillar and 13 m is required for barricading the filled-in section, 180 m can be used for emplacing the packages. With a package length of 6.2 m and a distance between the packages of approx. 1 m, a tunnel can accommodate 24 packages.

If all the tunnels of an emplacement connection drift are occupied by packages and filled in, then the emplacement connection drift, the parallel and flanking galleries, as well as the ventilation galleries (if they are no longer required) are filled in and closed by dams. Table 2-6 shows the most important data of an emplacement field.

At the same time as emplacement is being effected, the next sector of the emplacement field relative to the shaft area is opened up. The galleries are driven by a cutting tunnelling machine. The debris is either removed by direct belt feed and transportation via the conveyor system as stowing material to the emplacement location, a hopper area or the pit bottom at Shaft I. Or alternatively

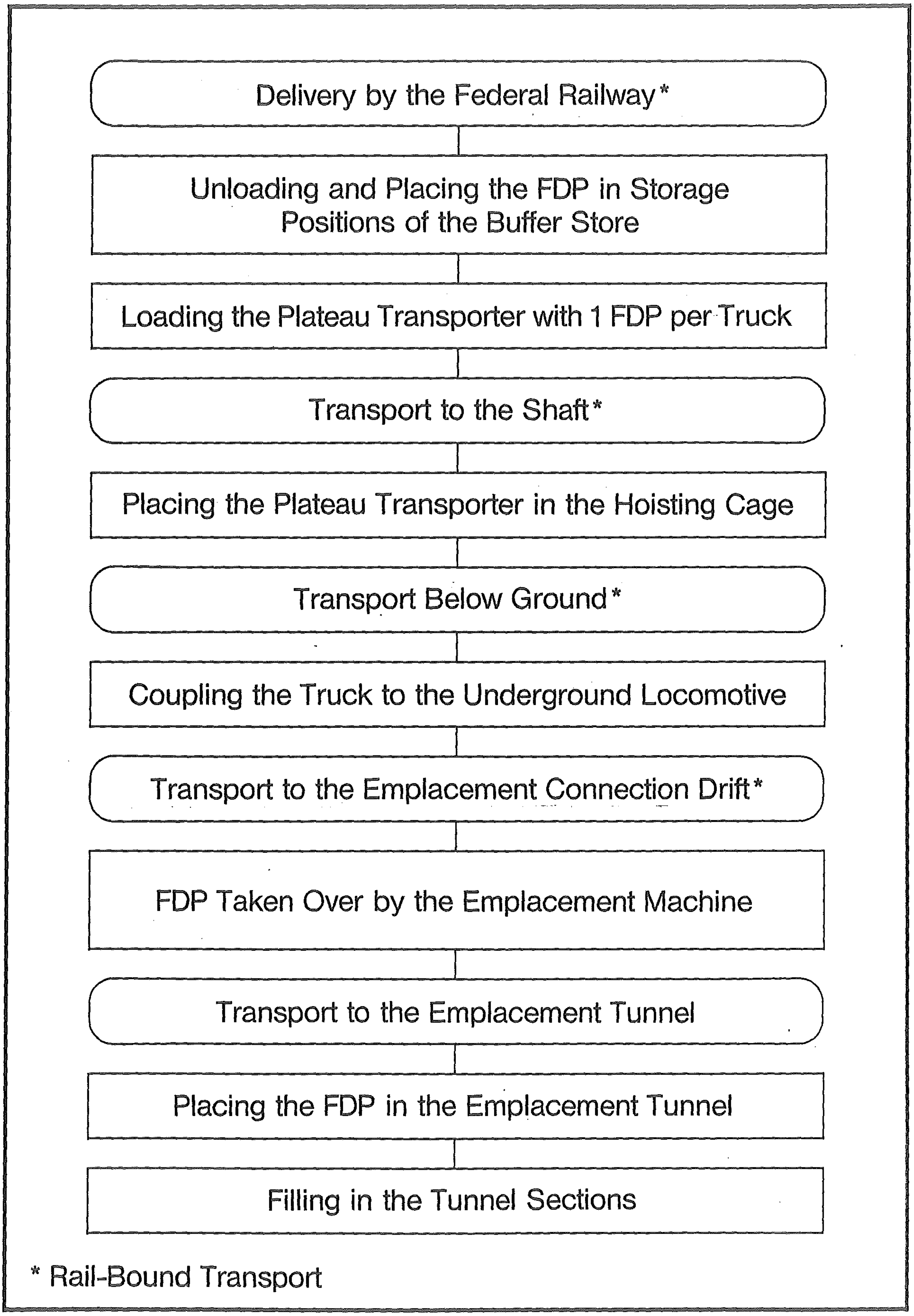


Figure 2-1: Diagram of the Emplacement Sequence

a shovel loader takes over the debris from the tunnelling machine and transports it to the belt feed. All transportation of debris in the emplacement sector is railless and is effected without exception through the connection drifts to the access gallery not used for emplacement transport. The maximum distance covered by the shovel loader to the belt feed is approx. 300 m. The hopper area is a maximum of 2 km from the emplacement location on the access gallery.

| | |
|---|---|
| Width of the Pillar Between the Access Gallery and the First Emplacement Tunnel . . . . . . . . . . . . . . . . . . . . . . | 15 m |
| Width of Pillars Between the Emplacement Tunnels . . . . . . . | 10 m |
| End Pillar Between the Emplacement Tunnel and Next Connection Drift . . . . . . . . . . . . . . . . . . . . . . | 7 m |
| Length of the Closure Plug of an Emplacement Tunnel . . . . . | 13 m |
| Effective Length of the Emplacement Tunnel . . . . . . . . . . . | 180 m |
| Package Length . . . . . . . . . . . . . . . . . . . . . . . . . . . . | 6.2 m |
| Distance Between Two Packages . . . . . . . . . . . . . . . . . . | approx. 1 m |
| Number of Packages Per Tunnel . . . . . . . . . . . . . . . . . . | 24 |

**Table 2-6: Dimensions in the Emplacement Field**

After terminating emplacement operation, all the tunnels and cavities are filled in and closed by plugs and dams. The shafts are also filled, whereby the natural geological structures are largely taken into consideration. Barriers of concrete and asphalt are also incorporated. Although the walls of the shaft are not removed, it will be impossible to use the shafts again.

### 2.2.4 Machines and Vehicles

The following machines and vehicles are available in the geological repository for developing the mine and filling in the tunnels after emplacement:

- cutting tunnelling machine
- shovel loader
- mechanical stowing machine.

These machines and vehicles are partly diesel-driven or they have electric engines and are railless. As self-propelled vehicles they can be equipped with a tachograph to record the distance covered, driving time and speed. The cutting tunnelling machine weighs approx. 80 t and can be equipped with an air-conditioned cab. However, this is not envisaged at the prevailing work temperature of 37°C. The shovel loader weighs approx. 25 - 30 t and is not suitable for transporting final disposal packages. The machines and vehicles described here can be used both in the FDP store as well as in the waste store. In addition to the vehicles mentioned, vehicles for inspection, transporting crews and material, clearing, loading and special purposes are used both in the mining and emplacement sector. The following are envisaged for emplacement operation:

- plateau transporter
- locomotive
- emplacement machines.

The plateau transporter is rail-bound and is not self-propelled. It weighs 8 t and carries a working load of 55 t. It is moved by a diesel- or battery-driven locomotive. However, a further plateau transporter is available with a lower load of 25 - 30 t for emplacing waste.

The only railless machine capable of picking up a package and transporting it independently is the emplacement machine. For reasons of redundancy, two emplacement machines are available. Their motor and brakes are designed for transporting packages over ascending and descending gradients of up to 1 %. The emplacement machines are not able to transport packages over sloping tunnels with a gradient of 10 - 12 %. The final design of the emplacement machines has not yet been decided. Two concepts are being discussed, on the one hand an articulated shovel loader with fork, also known as the Kiruna truck, and alternatively a portal lift truck on four stilts as e.g. used for container transport.

### 2.2.5 Ventilating the Geological Repository

Fresh air is brought in via the debris transport shaft to the emplacement floor and is then fed into the emplacement and advance working operations via the access gallery. The emplacement tunnels receive special ventilation via air ducts during advance working and emplacement. Outgoing air is fed directly to the former exploratory floor via ventilation chutes at the ends of the connection drifts and is then directed to the emplacement shaft where it escapes. Package transport on the emplacement level also takes place in the fresh air flow. A monitoring of the exhaust air for radioactivity is envisaged at least for the exhaust shaft.

# 3 NP ASPECTS OF DIRECT FINAL DISPOSAL

## 3.1 Direct Final Disposal in Comparison to Waste Management by Reprocessing

### 3.1.1 Consequences of a Direct Final Repository as a Model for Third Countries

From the proliferation point of view there are two areas in the nuclear fuel cycle requiring special protection:

On the one hand there are the two sensitive steps of enrichment and reprocessing whose technologies can in principle be used to separate strategic nuclear material, and on the other hand the accumulation of sensitive nuclear material for example in storing separated plutonium or spent fuel elements.

The protection and control of sensitive technology is the subject of the London Guidelines in which the individual components to be protected are listed in detail. A possible abuse of the facilities themselves is covered by the various international safeguards agreements with the IAEA within the framework of the NP Treaty or bilateral agreements.

An accumulation of spent plutonium can result in a fuel cycle with reprocessing for example by delaying the expansion of nuclear energy programmes, e.g. for breeder reactors. Institutional models have already been developed based on Article XII A5 of the IAEA Statute envisaging an international plutonium storage system for excess separated plutonium. Amongst other aspects, storage of excess plutonium is envisaged as well as a reduction in the storage capacities at fuel element factories for reactor fuels containing plutonium.

The accumulation of plutonium in the intermediate storage of spent fuel elements has also been identified as a sensitive point in the nuclear fuel cycle. The ISFM Group, meeting within the framework of the IAEA, has suggested appropriate countermeasures /3-1/.

The accumulation of plutonium in direct final disposal is regarded as especially disturbing in many quarters with respect to the non-proliferation of nuclear weapons. In this connection the concept of a "plutonium mine" has been introduced /3-2/. Particularly on the part of the Europeans and Japanese, the inherent proliferation danger at such final repositories was pointed out at the International Nuclear Fuel Cycle Evaluation Conference (INFCE) since in principle later access by a state to the very large quantities of plutonium which would be present in a geological repository with spent fuel elements can never be ruled out. This is of special significance because access to the plutonium will become easier in the long term due to the decreasing radioactivity of the spent fuel elements and thus the strategic value of the material will increase.

In connection with the large quantities of stored plutonium and the long operational life of such a repository of approx. 50 years, it must be pointed out that notice to or termination of the NP Treaty cannot be ruled out in various countries. In this case the state thus has the legal possibility of excavating spent fuel elements from the direct final repository and separating the plutonium for atomic weapons. It can be assumed that notice to the NP Treaty by the Federal Republic of Germany is out of the question.

Furthermore, it is not possible to waive the application of safeguards for a certain quantity of nuclear material on the basis of bilateral agreements. On the basis of these bilateral agreements it could rather result that the contracting parties would be able to participate in formulating safeguards application in the long term, which could lead to a tightening of safeguards (prior consent). On the basis of these overriding proliferation aspects it seems difficult to discuss the establishment of such repositories as a model for worldwide application since other states without the appropriate contractual conditions for controlling non-proliferation (non-proliferation credentials) would be in a position to obtain long-term access to sensitive plutonium.

In examining the question of the extent to which a non-recoverability concept would hinder later access to sensitive plutonium it must generally be presumed that in principle there will always be technical possibilities of bringing an emplaced fuel element back into the light of day. The technical difficulties depend, amongst other aspects, on the final disposal medium and they are probably greater for disposal in salt than for other media. It must be remembered that not all countries have this storage medium available and thus different proliferation profiles would result in the corresponding countries. The unusually large quantities of plutonium would make it possible to create large nuclear programmes for atomic weapons.

### 3.1.2 Possibility of Terminating Safeguards

The criteria for terminating IAEA safeguards are laid down in Paragraphs 26(C) of INFCIRC/66 and 11 of INFCIRC/153 corresponding to Art. 11, Verification Agreement (VA):"...upon determination by the Community and the Agency that the material has been consumed, or has been diluted in such a way that it is no longer usable for any nuclear activity relevant from the point of view of safeguards, or has become practically irrecoverable" /3-3, 3-4/.

The conditions of Paragraph 11, INFCIRC/153 are thus not applicable to spent nuclear fuel. The INFCE Working Group 7 established in their concluding report /3-5/ that waste from the LWR fuel cycle (recycled and non-recycled) is relatively unattractive for weapons production. Depleted uranium must either be enriched or irradiated and reprocessed. Pu waste is difficult to recover because of the great dilution in glass or cement. In the opinion of the INFCE, both types of waste probably correspond to IAEA criteria for terminating safeguards.

Since it becomes easier to handle spent FE's from the LWR cycle without recycling due to decreasing fission product activity, this is the type of waste in the LWR fuel cycle which, according to INFCE, is more attractive with respect to diversion. The easier recovery of fissionable material by reprocessing is in contrast to the fact that in a final repository in salt recovery of the final disposal package in the course of time will not be made easier in the foreseeable future due to the high temperatures occurring in the long term.

The extent to which future technologies will alter this assessment does not only depend on the development of highly sophisticated technologies for the enrichment and recovery of recycled nuclear material but also on technical progress in mining engineering. At this moment in time, the question of long-term safeguardability arises in connection with the direct final disposal of spent nuclear fuels in a suitable geological formation. The essential aspects for terminating safeguards, as well as for long-term safeguarding, are listed in Table 3-1.

| Termination of Safeguards | Long-Term Safeguards |
|---|---|
| Non-Recoverability (not fulfilled without further provision) | Novel Problem |
| Degree of Dilution of the Fissionable Material | Cancellation of Membership in the NP Treaty |
| Solution Pursuant to INFCIRC/153, Paragraph 35 or VA, Art. 35 Conceivable for Such Types of FE Not Envisaged and Not Economic for Reprocessing | Duration of the NP Treaty until 1995 |
| | NP Credibility |
| | Model Character of the Direct Final Repository |

**Table 3-1: Termination of Safeguards Measures and Long-Term Safeguards: Essential Aspects**

### 3.1.3 Considerations on a Final Repository for HAW and Spent Fuel Elements

For certain kinds of spent fuel elements (e.g. AVR, THTR or special types of light-water reactors) reprocessing is either not envisaged or not economical. For such fuel elements direct final disposal is therefore necessary. The question thus arises whether a termination of safeguards can be possible for such nuclear material. If the quantities of spent fuel elements were to be small in relation to highly active waste, which would also be taken into the final repository, then - although the conditions of Paragraph 11 are not fulfilled - Paragraph 35 of INFCIRC/153 or Art. 35 VA could come into effect, which says:

> "...Where the conditions of that paragraph are not met, but the State considers that the recovery of safeguarded nuclear material from residues is not for the time being practicable or desirable the Agency and the State shall consult on the appropriate safeguards measures to be applied. It should further be provided that safeguards shall terminate on nuclear material subject to safeguards under the Agreement under the conditions set forth in paragraph 13 above, provided that the State and the Agency agree that such nuclear materil is practicably irrecoverable."

A termination of safeguards is therefore not impossible in principle, an application of simplified safeguards is conceivable at any rate.

### 3.1.4 Extrapolation of IAEA Discussions on Sensitive Facilities to a Direct Final Repository

Recent discussions at the IAEA in connection with the implementation of safeguards concepts for sensitive facilities in reprocessing and enrichment have indicated that concepts making intensive use of containment/surveillance systems are not acceptable /3-6/. Since precisely this conception with intensive C/S could be of essential significance in the case of a direct final repository, a conflict can be expected here. The IAEA would have to make considerable cuts and reorientations in their previous safeguards philosphy if this problem is to be solved. Only a few problems can be mentioned here such as design verification, availability and reliability of instruments, verification of nuclear material in the case of instrumentation failure, internal diversion etc.

In spite of all these difficulties it must be seen that pursuant to the safeguards agreement, e.g. INFCIRC/153, all nuclear facilities, such as a direct final repository for spent fuel elements, would in principle have to be internationally safeguardable. However, in this case, considerable cuts would have to be made for such a safeguards concept in the "effectiveness" demands as currently discussed at the IAEA.

## 3.2 Results of NP Discussions in INFCE

Since about 60 nations and various international organizations, such as the IAEA, participated in INFCE the results and considerations of this conference are of particular significance for further approaches. This is especially true since the numerous previous discussions were combined and extended at INFCE. Thus INFCE Group 7 "WASTE MANAGEMENT AND DISPOSAL" concerned itself with the problems of safeguards in final repositories for spent fuel elements, the salient points of which will be given in the following.

Only waste containing U-235, U-233 and plutonium is of significance from a safeguards point of view. Other transuranic elements, such as neptunium and americium could also be of significance in future. Depending on their content of nuclear material the following categories of waste are differentiated in the INFCE considerations:

(I) Waste in the form of depleted uranium, natural uranium or low enriched uranium ( < 20 % U-235), so-called non-HEU waste.

(II) Highly active waste containing plutonium (or U-233 in the thorium cycle) and U-235.

(III) Waste with a low plutonium content and low content of high-enriched uranium, so-called HEU waste.

Spent LWR fuel elements thus fall into waste category (II). The flow of nuclear material in the fuel cycle can be quantified from the safeguards aspect with the aid of the concept of the "significant quantity". In the case of uranium waste in category (I), the significant quantity is 75 kg of U-235. In the case of plutonium and HEU waste the significant quantities are 8 kg for plutonium and U-233, and 25 kg for U-235. ( ≥ 20 %). These values also correspond to the guidelines for target quantities suggested by the IAEA. If one finally also considers that the waste is generally not present in the form of an open flow but rather packed in containers then the concept can be meaningfully characterized as "target batch". This is taken as the number of waste containers which together contain a significant quantity of nuclear material. In the case of LWR fuel, two spent fuel elements form a target batch.

The most attractive target for a diversion of nuclear material is represented by the spent fuel from the light-water reactor once-through cycle in the waste categories under consideration. The high radioactivity of the fission products initially functions as a self-protection for the fuel, thus making handling of the material more difficult. Moreover, reprocessing technology is required to separate the fission products and actinides, as well as to separate uranium and plutonium. However, after a correspondingly long storage period the radioactivitiy is significantly reduced and access to the plutonium after recovery becomes easier. Nevertheless, if the spent fuel elements are at that time enclosed in suitable containers in a final repository deep in the geological substratum at a salt temperature of 120°C then this makes recoverability and thus access to plutonium more difficult.

The remaining types of waste in category (II), as well as the waste in categories (I) and (III) do not represent attractive diversion targets in the view of INFCE. Safeguards measures for spent nuclear fuel in a final repository consist of accountancy and verification from the time of unloading from the reactor until emplacement in the salt dome or a different geological formation. The monitoring of loading and unloading activities by inspectors and/or television units is currently state of the art of IAEA safeguards. The automatic safeguarding of fuel movements in a repository is currently being developed, in the same way as non-destructive analysis (NDA) for determining the fuel burn-up or plutonium content.

All processes from storing spent fuel until emplacement in the final underground repository are safeguards-relevant. According to the INFCE discussions, the following demands must be made:

(1) Surveillance of final disposal canister loading, item counting of the fuel elements changing to item counting of the final disposal packages. A tamper-resistant seal on the FDP would be able to detect attempts at breaching the integrity of the package;

(2) counting the fuel elements or final disposal packages before and after each transport step;

(3) containment/surveillance and verification of the FDP from receiving the package until emplacing it in the final repository;

(4) containment/surveillance in order to ensure that there is no material retransport (possibly supported by monitors to detect the movements of radioactive material);

(5) inspections to verify the plant design in order to rule out the existence of clandestine transport paths, stores or equipment.

Three phases can be differentiated in safeguards measures with respect to a direct final repository:

During the first, or active, phase of the geological repository, item counting, inventory verification and surveillance are applied.

The second, or passive phase begins when individual areas of the repository are filled in again after emplacing the final disposal packages. Since during this phase recovery of waste becomes increasingly more difficult due to the filling in and the associated enlargement of the containment, the safeguards activities would be shifted from item counting to containment/surveillance after agreement between the IAEA and the operator.

The third, or post-operational phase, begins with the closure of the geological repository. It must be established by surveillance measures and periodic inspections of the area in question that no attempts at recovery have been undertaken.

After deactivating the final repository the degree of safeguards measures will be able to be reduced according to the concluding report of INCFE Working Group 7, pages 101 and 102, namely for the following reasons. Assuming there was an incentive to recover nuclear material from the shut-down repository if a considerable fraction of the emplaced nuclear fuel were to be recovered then this would practically mean reactivating the geological repository, associated with considerable efforts: drillings, shaft construction, ventilation, transport of excavated material, canister transport etc. In this case it would take 12 - 18 months before nuclear material would begin to emerge from the final repository. Such an undertaking would thus be easily observable. On the other hand, analyses have indicated that the recovery of a few final disposal canisters would be possible within a brief period (8 - 10 weeks). However since even for this undertaking, whose costs would amount to roughly $ 25 million, several large drilling facilities would be required which could hardly be concealed. This is, however, not directly transferable to the reference concept since in the analysis quoted in the INFCE report studies were undertaken for a final disposal canister 35 cm in diameter. Several of these canisters would therefore be required for a significant quantity of nuclear material.

In the long term the effectiveness of safeguards measures is questioned by INFCE (Concluding Report Group 7, page 101) since the post-operational phase lasting for centuries will be determined by numerous, hardly foreseeable factors such as:

- alterations in the institutional and social system,
- large inventory of fissionable material in repositories for spent FE's,
- decrease in radioactivity and thus better possibilities of recovering the fissionable material,
- development of new technical safeguards measures (i.e. processes and equipment),
- possible technological developments to accelerate the recovery of very diluted waste,
- degree of integrity of canisters with spent FE's in shut-down geological repositories and possibilities of recovery,
- later incentives for recovering the fissionable material from spent fuel for energy generation purposes.

No detailed predictions can be made about most of these factors. It is therefore not possible from current perspectives to make a decision on the possibility of monitoring a direct final repository in the post-operational phase or terminating safeguards.

# 4 APPLICATION OF IAEA SAFEGUARDS REGULATIONS TO THE REFERENCE CONCEPT

## 4.1 Political and Technical Boundary Conditions

### 4.1.1 Legal Bases for Safeguards

In the Federal Republic of Germany the tasks of international nuclear material safeguards - conditioned by the commitment to the European Atomic Energy Community (EURATOM) and the Non-Proliferation Treaty (NP Treaty) - are undertaken by two institutions:

- the Commission of the European Communities and
- the International Atomic Energy Agency (IAEA).

#### 4.1.1.1 The EURATOM Treaty

The objective of the treaty establishing the European Atomic Energy Community is a common market in the sector of the peaceful uses of nuclear energy; the major aspects being of equal priority in the assured supply of ores and nuclear fuels, promotion of research and the non-proliferation of nuclear weapons. The following boundary conditions can be derived from the EURATOM Treaty /4-1/ for direct final disposal:

- The material in the final disposal packages is special fissionable material and property of the European Atomic Energy Community.
- The Commission of the Community is obliged to safeguard the material with the aim of convincing themselves that it is being used for no other purposes than those specified by the users.
- The Commission inspectors shall have access to all locations, documents and persons related to the use or storage of nuclear material at all times.
- A purely national solution to the problem of the direct final disposal of spent fuel elements cannot be derived from the articles of the EURATOM Treaty quoted in detail in the following.

The aims and procedures of nuclear material safeguarding by the Commission of the European Communities are specified in detail in Chapter VII of the EURATOM Treaty. Safeguards are accordingly based on nuclear material accountancy, reports to EURATOM and the unimpeded access of EURATOM's inspectors to all nuclear facilities.

Pursuant to Art. 79 it is incumbent upon the operator of a nuclear facility to keep and present records of operational processes in the utilization or generation of materials subject to safeguards, thus enabling account to be kept of these materials. This is also valid for transportation of these materials. Whoever shall erect or operate a nuclear facility must inform the Commission of the plant design, insofar as this is necessary for the Commission to fulfill its tasks (Art. 78). The tasks of the Commission arise in part from Art. 77. Pursuant to this, it must ensure by appropriate safeguards:

- that the nuclear materials are not used for any purposes other than those envisaged;
- that the regulations concerning supply and all special safeguards obligations (prior consent) undertaken by the Community are observed.

The safeguards comprise ores, source materials and special fissionable materials. Pursuant to Art. 81 the Commission inspectors shall have access to all places and data and to all persons professionally concerned with materials, articles of equipment or facilities subject to safeguards at all times.

Article 86 says:

Special fissile materials shall be the property of the Community.

The Community's right of ownership shall extend to all special fissile materials which are produced or imported by a Member State, a person or an undertaking and . . . are subject to safeguards.

Whereas the proprietary rights of the Community to all special fissionable materials are laid down in Chapter VIII (Art. 86), Chapter VI regulates the supply of the member states with ores, source materials and special fissionable materials:

- In order to ensure a common supply policy according to the principle of equal access to the sources of supply, an agency was established to direct rights to the materials mentioned above generated on the territory of the member states. It has the exclusive right to conclude contracts on the supply of these materials from countries within and without the Community. (Art. 52).

- Pursuant to Art. 57, the rights of the EURATOM Supply Agency comprise the acquisition of

  a) rights to the utilization and consumption of special fissionable materials and

  b) proprietary rights in all other cases.

- Pursuant to Art. 62, Subsection 1, the Agency exercises its rights to the special fissionable materials generated in the member states in order to:

  a) cover consumer demand

  b) store these materials itself or

  c) export them.

In Art. 62, Subsection 2 the possibility is conceded of leaving these materials and the residues suitable for reprocessing with the producer so that they can be stored with the consent of the Agency. Furthermore, attention should be drawn here to Art. 80 of Chapter VII (Safeguards) according to which the Commission may demand that all excess special fissionable materials be deposited at the Agency or in other repositories subject to safeguards.

#### 4.1.1.2 Effects of the NP Treaty

In order to fulfill the obligations of the Non-Proliferation Treaty the non-nuclear-weapons states of the European Atomic Energy Community concluded an agreement (Verification Agreement) with the IAEA and EURATOM in 1973. This agreement (VA) essentially corresponds to the IAEA standard agreement INFCIRC/153. The basis for safeguards in the sector of the peaceful uses of nuclear energy is created for the nuclear weapons states of the Community by corresponding agreements.

Subsidiary Arrangements are appended to the Verification Agreement in which, amongst other aspects, inspection activities and efforts are determined on a model basis. The Verification Agreement and the Subsidiary Arrangements have the character of treaties concluded between the states, EURATOM and the IAEA, in which EURATOM and its member states undertake obligations to the IAEA. In order to be able to fulfill these obligations EURATOM adapted its safeguards system to the new requirements. This was implemented by directive no. 3227/76 /4-2/ replacing the old directives no. 7 and no. 8.

The Subsidiary Arrangements comprise the Facility Attachments separately compiled by EURATOM and the IAEA for each nuclear facility. These Facility Attachments (FA) are the basis of the special safeguards provisions determined by EURATOM for each facility.

#### 4.1.1.3 Safeguarding by IAEA and EURATOM

EURATOM undertakes safeguards in the nuclear facilities of the Community pursuant to the EURATOM Treaty and EURATOM directive no. 3227/76. IAEA safeguards are based on the NP Treaty and the Verification Agreement. Details of this implementation are determined in the Subsidiary Arrangements and the Facility Attachments (FA). The EURATOM special safeguards provisions transfer safeguards based upon the FA to the EURATOM level, insofar as these measures are not already determined by the EURATOM directive.

EURATOM and IAEA cooperate in detecting possible diversions of nuclear material for nuclear explosive devices. To this end

- in discussing the FA, EURATOM communicates the facility data provided by the facility operators to the IAEA with the exception of information to be commercially protected,
- EURATOM communicates to the IAEA in a modified form the reports on nuclear material it has received from the operators of the nuclear facility,
- the IAEA obtains the right to monitor part of EURATOM's inspections.

The IAEA verifies the results of EURATOM's safeguards insofar as these are implemented on the basis of the Verification Agreement and the FA's. The following principles are valid for the IAEA verification activity (see also Table 4-1):

1. The concept of preventing diversion used in the NP Treaty is restricted to the timely detection of a diversion and the deterrent effect.
2. Restriction of safeguards to nuclear material, i.e. the facilities themselves are not monitored.
3. Principle of applying safeguards only at certain strategic points in the flow of fissionable material.
4. Restricting the IAEA to verifying the results of the EURATOM safeguards system.
5. Application of safeguards in such a way that the economic and technical development in a state or international cooperation in the field of nuclear energy is not impeded.
6. In certain cases substantiated by the IAEA, it shall obtain the right to undertake its own independent special inspections.

| |
|---|
| Preventing diversion by a deterrent effect (timely detection) |
| Nuclear material safeguards (not: facility safeguards)<br>by measurements as well as containment/surveillance |
| Strategic points principle |
| Verification of EURATOM results (reports) |
| No impediment to the peaceful uses of nuclear energy |
| Right to own independent inspections |

**Table 4-1: Principle of IAEA Safeguards Pursuant to the Verification Agreement**

### 4.1.2 Boundary Conditions for Implementing Safeguards

On the basis of the principles described above, the following problem areas result as boundary conditions for the development of the safeguards concept:

#### 4.1.2.1 By EURATOM

1. Clarification of the question of the extent to which the unrestricted utilization and consumption rights of a member state exercised on the basis of possessive rights to nuclear material (Art. 87) are restricted by the proprietary rights of the Community. It must be assumed that in the case of final disposal conceived of as non-recoverable this decision on disposition must be regarded as irreversible and thus requiring at least the consent of the Community as the owner of the material. Various models are conceivable in which the owner and the possessor share responsibility for and implementation of final disposal, e.g.:

- The Community declares that it does not regard its proprietary rights as impaired by the non-recoverable final disposal of the material and cedes responsibility for and implementation of final disposal to the member state.

- The member state implements national final disposal on behalf of the Community, whereby conditions must be expected to be imposed by the Community.

- Final disposal is carried out as a multinational undertaking by the Community itself, the member state making territory and infrastructure available (cf. Art. 80, Deposition).

Variant 1 underestimates the long-term proliferation aspects of a direct final repository. In this case the interest of the Community does not concentrate on proprietary rights but rather on effective safeguards.

Variant 2 corresponds most closely to the interests of the Federal Republic of Germany. Retention of ownership and safeguards is ensured on the part of the Community and is internationally verifiable. A national final repository is also more advantageous from the point of view of acceptance than

Variant 3. This includes the possibility of a final disposal of foreign final disposal products from EURATOM states and thus presents significant acceptance problems. In view of the geographical and political situation of the Federal Republic of Germany, Variant 3 cannot be desirable.

2. EURATOM requirements with respect to nuclear material accountancy and the report system are largely in agreement with IAEA demands.

3. With respect to regulations for inspection activities, EURATOM's inspection rights are comprehensively determined in the EURATOM Treaty Art. 81.

4.1.2.2 By IAEA

The position with respect to IAEA safeguards must be considered in much more detail. The following problems are to be discussed and clarified on the basis of the Verification Agreement:

1. Quantification of timeliness of detection and significance of nuclear material quantities.

2. Determination of strategic points with clarification of access rights for IAEA inspectors.

3. Clarification of the problem of the extent to which the IAEA can implement safeguards independently of EURATOM.

4. Clarification of the question of the extent to which safeguards can be terminated if proof of non-recoverability of the material is furnished.

These points will in part only be finally determined in the Facility Attachments, however they must be considered in the safeguards concept of the facility.

Re 1: Quantification of timeliness of detection and significance of nuclear material quantities.

The IAEA detection goals are described by the following parameters still to be quantified:

- significant quantity
- timeliness of detection
- detection probability of a diversion
- probability of false alarms.

The quantification of these variables, as well as the total inventory and its strategic significance, serve the IAEA as a basis for developing its safeguards model for the facility to be safeguarded. In implementing the model for a specific facility, the inspection goals aimed at for the facility in question will be derived from these detection goals.

The detection goals depend greatly on the type and composition of the material to be safeguarded. If one bases the products for final disposal on LWR fuel elements of the Biblis type then the data listed in Table 4-2 result for the irradiated FE's.

| Fissionable Materials | FE | FDP | Annual Increment of the Final Repository | Total Inventory of the Final Repository after 50 Years |
|---|---|---|---|---|
| U-235 | 4.1 kg | 12.3 kg | 5.4 t | 268 t |
| Pu-239 | 3.1 kg | 9.3 kg | 4.0 t | 201 t |
| Pu-241 | 0.4 kg | 1.2 kg | 0.6 t | 11 t |
| Total | 7.6 kg | 22.8 kg | 10.0 t | 480 t |
| | | | | |
| Uranium | 506.0 kg | 1518.0 kg | 663.0 t | 33,140 t |
| Plutonium | 5.3 kg | 15.9 kg | 7.0 t | > 212 t |
| Fission Products | 22.0 kg | 66.0 kg | 28.8 t | |

**Table 4-2: Final Repository Inventory of Spent FE's /4-3/**

The variables currently set as guidelines by the IAEA for significant quantities (SQ) are 8 kg for plutonium and 75 kg for low enriched uranium U-235; that means that each final disposal package contains more than the significant quantity of plutonium.

Bulk handling facilities (BHF) are classified by the IAEA according to a nuclear material index (NMI). This is based on the facility throughput or the facility inventory, expressed in weighted significant quantities (WSQ). The inspection and verification activities of the IAEA are concentrated on facilities with a high nuclear material index. In the Safeguards Implementation Report (SIR) for 1981 the following statistical maximum values are given for the safeguarded BHF's in order to characterize the spread:

- max. plutonium inventory (in significant quantities) 137
- max. annual plutonium throughput (in significant quantities) 167

In the case of a direct final repository these values would already be considerably exceded in the first year of operation, as can be seen from the following summary of significant quantities:

| Pu | U | |
|---|---|---|
| 2 | 0.16 | Final Disposal Package |
| 875 | 71 | Annual Increment of the Final Repository |
| > 26,500 | 3573 | Total Inventory of the Final Repository after 50 Years |

Simply from the quantity of material to be safeguarded, the final repository represents a new dimension for safeguarded facilities.

The IAEA does not specify any fixed value for detection time. It is aimed to achieve a timeliness goal of three months in the case of storage ponds for spent fuel elements in LWR facilities containing the same kind of fuel elements. It would have to be possible to take over this value for the final repository.

With respect to the probability of detection, a value between 90 and 95 % is usually aimed at, the probability of false alarm being assumed as smaller than or equal to 5 %.

However, a probability of false alarms of approx. 5 % is not acceptable for the final repository. On a computational basis this would mean 10 false alarms during the operating time with an inspection period of three months and a repository operating life of 50 years. It must be assumed that in the case of a final repository the clarification of a false alarm, i.e. the reopening of tunnels already filled in, is impossible or only possible with unjustifiably high expenditure. The fact that the material is no longer accessible to direct verification, or only with excessively great efforts, requires that a safeguards system for the facility be

a) resistant to failure and

b) resistant to false alarms.

This can probably only be achieved by an appropriate redundancy in safeguards measures.

Other materials which could be considered for direct final disposal are e.g. fuel elements from thorium high-temperature reactors. Reprocessing of these fuel elements is not currently envisaged or economical. A reference concept is currently being developed for the disposal of these fuel elements.

Re 2: Determination of strategic points with clarification of access rights for IAEA inspectors.

In accordance with the concept of the Verification Agreement, nuclear material safeguards are based on the principle of material accountancy and material balancing, as well as auditing and material verification:

- the facility operator keeps account of the changes in reserves and the reserves of nuclear material in his facility and prepares a balance sheet at at least annual intervals.

- Inspectors from the safeguards organizations examine the balance sheet and verify the data recorded in it.

The locations where data are verified and the locations where containment and surveillance measures are implemented are termed strategic points. It is a basic principle of nuclear material safeguards pursuant to the Verification Agreement that the activities of the IAEA inspectors and their rights of access are normally limited to the strategic points in the facilities. With respect to the inventory and verification of reserves, the safeguards model is based on assumptions of significance for practical implementation. The most important is:

During inventory taking all batches of nuclear material are to be presented at the key measurement points determined for the inventory, irrespective of the quantity of nuclear material they contain so that they can be verified by the safeguards organization. The verification is generally restricted to identification and visual checking of all batches and random measurement of individual batches.

Verification can either be direct, i.e. by verifying the values specified by the operator by means of measurements, or indirect, e.g. by examining attached seals and verifying the containment.

This basic safeguards model can only be technically applied to a very limited degree in the final repository. As soon as the final disposal canister is packed in or the tunnel is filled, a direct verification can no longer be technically implemented so that this basic model meets with considerable restrictions when applied to the direct final repository. Inventory taking is therefore only possible indirectly, for example according to the following pattern:

If there are no indications that the material is no longer there, then it can be concluded that it is still present and the results of the last verifications are therefore still valid.

This form of indirect material verification can only be acceptable for the safeguards authority if they can assume that all conceivable diversion pathways are safeguardable with sufficient reliability. To this end additional strategic points will have to be defined.

According to the definition of the Verification Agreement (Art. 98) strategic point means a location selected in assessing facility data where under normal conditions and in conjunction with information from all the strategic points necessary and sufficient information for implementing safeguards is accessible and can be verified; a strategic point may be a location where key measurements for material accountancy are implemented and where measures for containment and surveillance are undertaken.

Emplacing spent fuel elements only represents a small fraction of the handling processes in the final repository. Apart from the emplacement of fuel elements, it is envisaged that radioactive waste will also be deposited in the geological repository. Waste emplacement is in all cases independent of FDP emplacement, although the facilities above ground and the shaft equipment is used for both emplacement materials. Waste materials are delivered in barrels of 200 or 400 l with concrete shielding. It is envisaged that approx. 27,500 packages will be emplaced per year. Waste packages will be emplaced simultaneously with the FDP's. The same mining machines will be used for developing the waste emplacement field. There is no difference in the machines for the two fields. Waste packages are no longer subject to safeguards. Their emplacement need not be safeguarded.

However, the simultaneous and adjacent emplacement of radioactive waste must be regarded as an interference factor from the safeguards aspect. Due to waste emplacement, non-safeguarded activities not subject to disclosure are implemented above and below ground which could make detection of a diversion more difficult or facilitate concealment of a diversion. In order to develop a safeguards concept and determine the strategic points and the IAEA inspectors' rights of access it is therefore essential that all activities in the geological repository can be clearly differentiated by the safeguards authority. Due to the necessity of having to verify the material indirectly the completeness of their information with respect to all activities regarding material is of paramount importance for the safeguards authority. The safeguards authority can only state that they have no indications that the material to be safeguarded is no longer present if no activities requiring explanation or open to misinterpretation have been recorded in the vicinity of final disposal package emplacement. This can possibly lead to surveillance and access rights having to be granted to IAEA inspectors for processes, facilities and locations of waste emplacement in order to make all relevant activities at the geological repository transparent to them.

Re 3: Clarification of the question of the extent to which the IAEA may implement safeguards independently of EURATOM.

The Verification Agreement determines that EURATOM and IAEA shall avoid any unnecessary duplication of work in implementing safeguards. The IAEA implements safeguards activities in such a way that, insofar as it can achieve the objectives of its inspections, it monitors the activities of the EURATOM inspectors and verifies EURATOM's assessments. Apart from other aspects, the IAEA's verifications include independent measurements and surveillance. Considering the order of magnitude of the safeguards problem it is to be assumed that the IAEA will strive for the greatest possible independence from EURATOM's safeguards activity. This could mean e.g. that C/S measures would be applied redundantly for EURATOM and IAEA, or jointly evaluated, as is currently the case e.g. in camera monitoring in LWR facilities.

Re 4: Clarification of the question of the extent to which safeguards may be terminated if proof of non-recoverability of the material is furnished.

The criteria for releasing material from safeguards are described in Art. 11 of the Verification Agreement: "Safeguards under this Agreement shall terminate on nuclear material upon determination by the Community and the Agency that the material has been consumed, or has been diluted in such a way that it is no longer usable for any nuclear activity relevant from the point of view of safeguards, or has become practically irrecoverable."

With respect to evaluating non-recoverability, the type of emplacement is undoubtedly of decisive significance, and the emplacement envisaged in the reference concept with lost shielding makes it considerably more difficult to classify the material as "non-recoverable".

The operational phases of the repository must also be considered in evaluating recoverability. In view of the envisaged emplacement with lost shielding it will probably be very difficult to provide evidence that the material is already non-recoverable in the operational phase of the final repository, i.e. after the individual emplacement tunnels have been filled in.

Evaluation of recoverability in the post-operational phase of the repository, i.e. after the shafts have been filled in, must undoubtedly be regarded in a different light. If the material were still to be classified as subject to safeguards even in the post-operational phase of the repository then this would require safeguards for an unforeseeable length of time. This also represents a completely new dimension for international safeguards which in the case of conventional facilities can generally be terminated with removal of the inventory or at the latest with closure or decommissioning of the facility. Safeguards ad infinitum would probably also require new safeguards techniques which still have to be developed.

### 4.1.3 Current Discussion

It is generally accepted that a safeguards concept on the basis of INFCIRC/153 requires further development, at least for certain types of facility. An extended safeguards concept has been compiled by the IAEA which, over and above the existing model, envisages additional strategic points in the material balance areas at which operational records will be kept by the operator and measurements on nuclear material implemented by the inspector, as well as observations of operational processes in progress. The implementation of safeguards according to this model which has been included in some facility attachments for nuclear facilities in the Federal Republic has only been accepted on the part of the Federal Republic on a trial basis and for a limited period. This is especially true of the IAEA demands for:

- establishment of additional strategic points to determine the flow of nuclear material within material balance areas
- access to operational records concerning the flow of nuclear material at the additonal strategic points
- execution of verification activities at the additional strategic points
- implementation of safeguards basically independent of EURATOM.

There is no statutory basis in the Verification Agreement for these safeguards activities accepted as a trial for a limited period of time.

## 4.2 Safeguards Concept

The total nuclear material inventory of the final repository is contained in individual identifiable items, the final disposal packages. The IAEA safeguards concepts for such facilities are based on item accountancy. Since in the case of final disposal packages there is no possibility of direct verification, e.g. by non-destructive assay methods (NDA), the following methods remain as applicable measures within the framework of nuclear material accountancy:

- item counting,
- item identification,
- verification of the integrity of the item.

It is assumed for the safeguard's concept of the final repository that the contents of the final disposal package have been verified in the conditioning facility before being placed in the bin. The final disposal package is subsequently sealed in the conditioning facility in such a manner that the validity of the final measurement can be extended for an unlimited period by verifying the integrity of the item. The data from this measurement are retained for the item as long as it is still subject to safeguards. After leaving the conditioning facility the material contained in the item is only verified by identity and integrity verification.

### 4.2.1 Final Disposal Canister

The final disposal package for the reference concept (three intact FE's per FDP) consists of four concentric shells:

- dry disposal bin
- canister body
- corrosion protection
- lost shielding.

The canister body and corrosion protection form the final disposal canister which is cast en bloc in a special process. The floor and lid of the FDC are screwed in and welded. The main aspect as far as safeguards are concerned is the external cladding, i.e. in the case of final disposal with lost shielding the subsidiary shielding of the FDP or in the case of borehole disposal the corrosion protection of the FDC.

A cast cylindrical body is used as the lost shielding, the bottom and lid of which are screwed in in contrast to the procedure in the case of the shells it encloses. Mounting points are envisaged in such a way that it is possible to seal the floor and lid openings. If electronic seals are to be applied then for their protection cavities or recesses are envisaged in which the seals can be mounted. As a back-up system for the sealing of the lost shielding a weldment verification of the corrosion protection (next shell underneath) can be envisaged. In the further considerations it is first assumed that the cast canister envisaged as the subsidiary shielding (the lost shielding) representing the external containment of a final disposal package, can be verified with respect to its integrity by visual checks and that the containment openings are protected by one or more seals verifiable in situ.

### 4.2.2 Nuclear Material Flow

The final disposal packages are transported via the public railway network of the Federal Railway. They are delivered in a type B flask designed for transport on public routes pursuant to the regulations. The incoming trucks are first parked in the buffer zone. Buffer capacity is designed for three working days, i.e. nine final disposal packages. The final disposal packages themselves are not yet accessible in the buffer zone since they are still in the transport flasks.

The trucks are driven from the buffer zone to the reloading area and the final disposal packages are drawn out of the flasks and loaded onto the rail-bound internal transport trucks (plateau transporter). The final disposal packages are transferred by means of a crane facility. The subsequent reception control procedure takes the form of a dose rate measurement, a wipe test, a visual check and registration. The integrity of the containment and seal of the lost shielding could also be verified. The plateau transporter is then driven to the shaft, loaded into the hoisting cage and transported to the emplacement level. At the emplacement level the plateau transporter is removed from the hoisting cage and driven to the emplacement tunnel. Underground rail-bound transport is terminated at the junction of the access gallery and the emplacement connection drift.

The final disposal package is then transferred from the plateau transporter to the emplacement machine, or taken up by the latter and (not rail-bound) driven to the emplacement tunnel. The canister is deposited by the emplacement machine at the emplacement location. After the filling material has been pneumatically packed the canister is no longer accessible. The material flow is shown diagrammatically in Fig. 4-1.

### 4.2.3 Preliminary Considerations on the Safeguards Concept

On the basis of the material flow sketched above, the following considerations can be established:

The individual final disposal packages can only be identified and verified after removal from the flask. This takes place after leaving the buffer store at the beginning of the emplacement process, immediately before reception control. It therefore does not seem to be meaningful to divide the facility into several material balance areas (MBA) (e.g. according to the criterion above ground/under ground). The material only resides above ground (buffer store) for a maximum of a few days and the establishment of a separate MBA for the area above ground would require additional identification and accountancy efforts without improving the safeguards possibilities. After reception checks, the emplacement of the final disposal packages is implemented as a continuous process without further intermediate buffering.

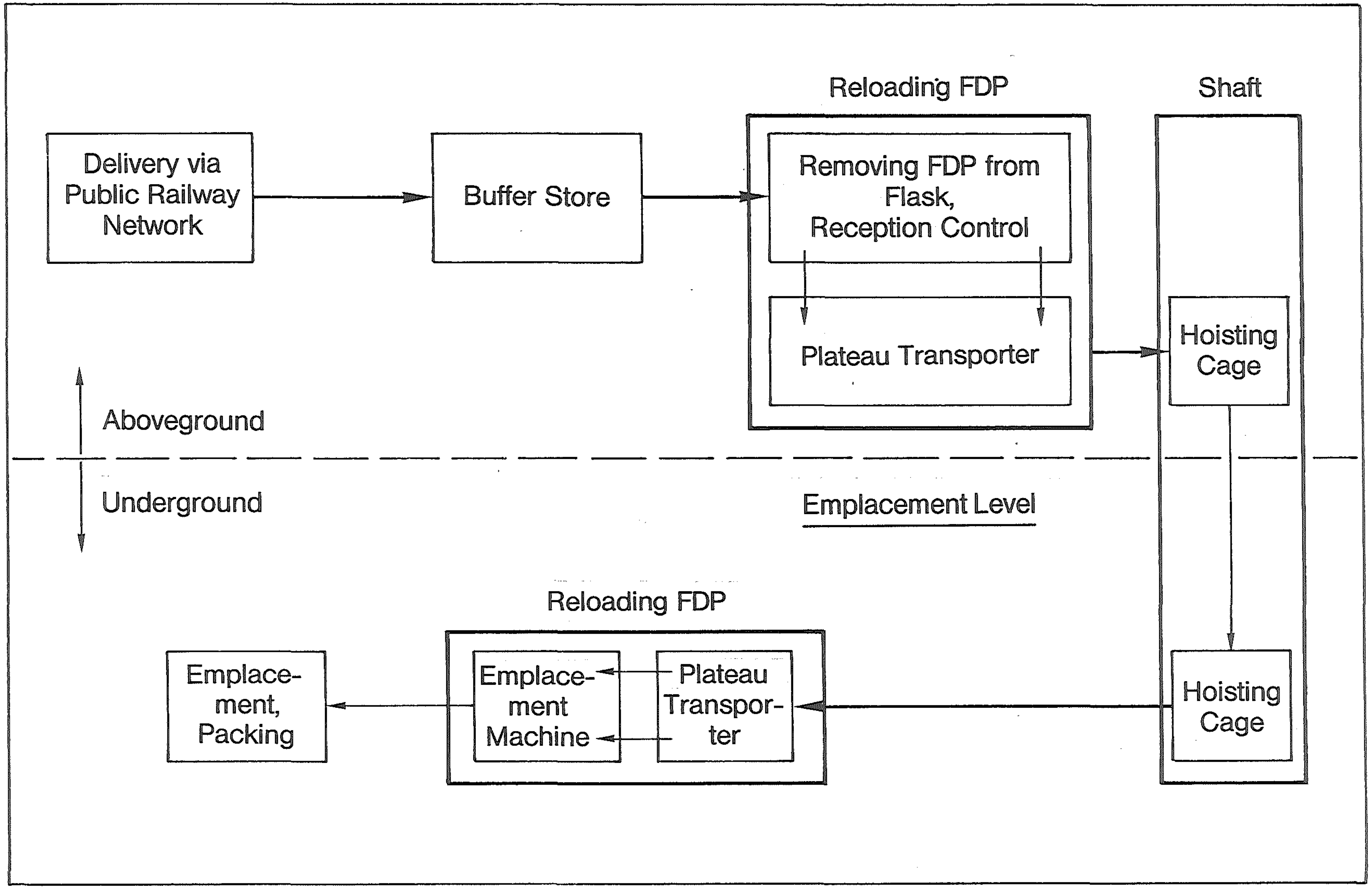


Figure 4-1: Material Flow Diagram

The last opportunity of identifying a final disposal package is after it has been deposited in the emplacement tunnel by the emplacement machine. After this the filling process begins and this part of the tunnel becomes inaccessible. It should be examined whether this last step (packing the canister) can be coupled to an acknowledgement signal for the functionality of the safeguards devices in order to increase the system's resistance to failure.

As long as the emplacement process, including packing the final disposal package thus rendering it inaccessible, proceeds as a continuous process continuous safeguards are also required to verify the material flow. The objective of safeguarding the material flow is to verify whether the declared material has been emplaced at the declared location. The possibility of verifying the identity and integrity of final disposal packages already deposited in the emplacement tunnel and of only filling the tunnel under observation after all emplacement processes have been terminated could make an essential contribution to simplifying safeguards. In this case continuous safeguarding of the emplacement work could be replaced by batch-oriented verification (one or more complete tunnels) of the outcome of the work. However, it is technically more difficult to backfill the tunnel after completing all emplacement processes and leads to a considerably higher dose rate for the operating personnel due to direct radiation.

With respect to nuclear material safeguards, the first subtask will be to ensure that the material flow proceeds in the declared manner; i.e. that the declared material is transferred to the declared location. This can largely be achieved by applying surveillance measures (camera and/or human surveillance).

The next subtask consists of ensuring that the emplaced material remains at the emplacement location until its final containment (sealing the emplacement tunnel or tamping the access gallery for fields already backfilled). Surveillance measures could also be employed to prevent recovery of the material via declared paths.

Special measures are necessary for the final safeguards subtask, namely of ensuring that no further clandestine entrances can be created to the tunnels already backfilled and tamped via which the material could be diverted, or that the material could be subjected to clandestine further processing within the geological repository after the tunnels have been backfilled. This form of diversion would admittedly involve great technical efforts, however it cannot be reliably ruled out. Since no indicators are currently available or known for reliably indicating such a diversion, the strategy for this safeguards subtask must consist in increasing the technical efforts required for clandestine diversion via these paths by appropriate measures to such an extent that this diversion risk can be reduced to an acceptable residual risk. Suitable measures could for example be comprehensive access concessions to all aboveground and underground facilities for inspectors.

### 4.2.4 Safeguards Concepts for Different Access Models

Three models are to be considered in the following differentiated by different access rights for the IAEA inspectors. In Model 1 access is restricted to the aboveground facilities, Model 2 comprises limited access to the underground facilities and Model 3 unrestricted access to all underground facilities.

#### 4.2.4.1 Access Model 1

Version 1

In this model the inspector's access is restricted to strategic points above ground. Strategic points (SP) are the key measurement points (KMP), the aboveground unloading facility and both shafts to the geological repository.

The essential element in this model is that after transferring the material underground recovery or an internal diversion within the repository is ruled out. By transferring the material underground it is thus released from safeguards and written off via KMP 2 (exemption from compulsory registration). Since according to this model there is by definition no longer any material subject to safeguards present after terminating emplacement activities, no safeguards are required for the post-operational phase either. The essential elements of this model are:

material balance areas

- the facility forms one material balance area

strategic points, being key measurement points

- for determining the flow of nuclear material
  - KMP 1 - entry, intake, cancellation of exemption (for rework material)
  - KMP 2 - exemption from compulsory registration
- for physical inventory taking
  - KMP A - buffer store

records system

- accounting for inventory changes
  - entry, intake at the time of entry
  - exemption from the compulsory registration at the time of transfer underground
- operating records contain the following data
  - place and time of emplacement for each FDP
  - type, place and time of backfilling/sealing measures

installations and installed devices

- seals on FDP's
- optical surveillance of FDP unloading aboveground
- optical surveillance/detectors at the entrances to the two shafts

strategic points for containment and surveillance measures

- FDP unloading aboveground
- entrance shaft 1
- entrance shaft 2

recording the physical inventory

- counting and identifying the items at key measurement point A

Safeguards applied:

- pre-operational phase
  - design verification before startup (only above ground)
- operational phase
  - identity and integrity verification of the final disposal package by the inspector at the entrance (reception control)
  - camera monitoring at the aboveground unloading facility to prevent undeclared unloading processes (replacement with dummies)
  - C/S measures (camera, detectors) at the strategic points shaft 1 and shaft 2 to prevent undeclared material flow (backflow)
- post-operational phase
  - no safeguards

Version 2

Version 2 of this model is only differentiated by the fact that the material under ground cannot be released from compulsory registration. KMP B thus takes the place of KMP 2 for inaccessible material below ground. The inventory is taken at this key measurement point by establishing on the basis of observations at the strategic points Shaft 1 and Shaft 2 that no material backflow has taken place. The material brought into the repository must therefore still be present there. Safeguards in the post-operational phase depend on whether requirements for releasing the material from safeguards have been able to be fulfilled at the closure of the geological repository. The essential elements of this version of the model are:

material balance areas

- the facility forms one material balance area

strategic points being key measurement points

- for determining the flow of nuclear material
  KMP 1 - entry, intake
- for taking the physical inventory
  KMP A - buffer store
  KMP B - all underground facilities, material inaccessible

records system

- recording inventory changes
  - entry, intake at the time of entry
  - exemption from compulsory registration at the time of closing the geological repository if termination envisaged on the part of the IAEA
- operating records contain the following data
  - place and time of emplacement for each FDP
  - type, place and time of filling in/sealing measures

installations and installed devices

- seals on FDP's
- optical surveillance of FDP unloading above ground
- optical surveillance/detectors at the entrances to the two shafts

strategic points for containment and surveillance measures

- FDP unloading above ground
- access Shaft 1
- access Shaft 2

taking the physical inventory

- counting and identifying items at key measurement point A
- establishing that no return flows have occurred via the SP's Shaft 1 and Shaft 2; concluding that the material brought in must still be present.

Safeguards applied:

- pre-operational phase
  - design verification before startup (above and below ground)
- operational phase
  - identity and integrity verification of the final disposal packages by the inspector at entry (reception control)
  - camera monitoring at the aboveground unloading facility to prevent undeclared unloading processes (replacement by dummies)
  - C/S measures (camera, detectors) at the strategic points at the two shafts to prevent an undeclared material flow (backflow)
- post-operational phase
  - termination of safeguards after backfilling all shafts, decommissioning of the aboveground facilities as well as demonstration of non-recoverability (if acknowledged to be impossible by means of mining technology)
  - routine examination of the site by visual inspections to safeguard against activities which could indicate a reopening of the geological repository or other measures for recovering the material.

The two versions of this model assume that the final geological repository itself can be regarded as a sufficient barrier so that measures ensuring

- that there are no undeclared containment openings through which the material could be recovered and

- a diversion of the material within the containment (reprocessing below ground) can be ruled out,

can be dispensed with.

#### 4.2.4.2 Access Model 2

This model comprises Model 1 and additional strategic points below ground. The strategic points below ground enable the inspector to safeguard the underground flow of material. Safeguarding the flow of nuclear material below ground can be undertaken at various levels of intensity:

- safeguarding the underground flow of nuclear material by camera monitoring and possibly recording instruments at the hoisting and transport installations with the possibility of human surveillance in the case of instrument failure,
- additional random human surveillance of emplacement processes,
- every final disposal package to be personally accompanied by the inspector from transport to the shaft until emplacement in the tunnel and backfilling of the tunnel section.

The same restrictions are largely applied to this model as to Model 1. It would have to be possible to terminate safeguards after backfilling the tunnel, or the final geological repository itself would have to be regarded as a sufficiently reliable barrier.

Access of the inspector to strategic points underground would admittedly considerably hinder a diversion in the final geological repository or out of the repository, however, it cannot be ruled out with sufficient reliability.

The essential elements of Model 2 are:

material balance areas

- the facility forms one material balance area strategic points being key measurement points

- for determining the flow of nuclear material
  - KMP 1 - entry, intake
  - KMP 2 - exemption from compulsory registration if safeguards termination envisaged on the part of the IAEA
- for taking the physical inventory
  - KMP A - buffer store
  - KMP B - tunnels not yet backfilled, underground
  - KMP C - backfilled tunnels, underground

records system

- recording inventory changes
  - entry, intake at the time of entry
  - exemption from compulsory registration at closure of the geological repository, if termination of safeguards possible
- operating records contain the following data
  - place and time of emplacement for each FDP
  - type, place and time of backfilling/sealing measures

installations and installed equipment

- seals on FDP
- optical surveillance of FDP unloading above ground
- optical surveillance/detectors at the entrances to the two shafts
- optical surveillance of FDP unloading below ground (pit bottom - access gallery, access gallery - emplacement connection drift and entrance to the emplacement tunnel)
- recording instruments / tachograph for the hoisting engine, plateau transporter (tractor) and emplacement machine (if available and necessary).

Strategic points for containment and surveillance measures

- FDP unloading above ground
- access Shaft 1
- access Shaft 2
- FDP unloading below ground (hoisting cage - access gallery and access gallery - emplacement connection drift)
- entrance to emplacement tunnel

taking the physical inventory

- counting and identifying items at the key measurement points A and B, if not yet backfilled
- integrity verification of the ends of the tunnels at key measurement point C by visual inspection; concluding that the emplaced material must still be present.

Safeguards applied:

- pre-operational phase
  - design verification before startup (aboveground and underground)
- operational phase
  - design reverification after driving a new tunnel
  - identity and integrity verification of the final disposal packages by the inspector at entry (reception control)
  - camera monitoring at the unloading facility above ground to prevent undeclared unloading processes (replacement by a dummy)
  - C/S measures (camera, detectors) at the strategic points at the two shafts to prevent undeclared material flow (backflow)
  - camera monitoring at the underground unloading points (from the hoisting cage on rails along the access gallery; from the plateau transporter on an emplacement machine without rails) to prevent replacement by a dummy
  - camera monitoring at the entrance to the emplacement tunnel to observe the emplacement process and prevent recovery until the tunnel has been sealed

  - recording the duration and speed of run in the case of the hoisting engine, plateau transporter (tractor) and emplacement machine as back-up measures for camera surveillance (if available and necessary)
  - inspector access to the strategic points underground either on a random basis or at any time.
- Post-operational phase
  - termination of safeguards after backfilling all shafts, decommission of the aboveground facilities as well as demonstration of non-recoverability (if recognized as impossible by means of mining technology)
  - routine examination of the site by visual inspection for safeguarding against activities which could indicate a reopening of the repository or other measures for recovering the material.

In the case of Model 2, the diversion possibility also remains as a residual risk e.g. of opening clandestine access to already backfilled tunnels or fields of the fuel element emplacement section from the waste emplacement area, diverting final disposal packages with a supplementary emplacement machine from the FE disposal area into the waste disposal area and either disguising them here as MAW, required for rework, for transport above ground, or further processing them in the waste section. Abuse of the waste disposal area for a diversion from the FE disposal area can be made considerably more difficult by permitting IAEA inspectors unhindered access to all facilities in the geological repository. This possibility is envisaged in Model 3.

4.2.4.3 Access Model 3

Model 3 comprises Model 2 and moreover also all underground facilities and installations as supplementary strategic points:

Strategic points for containment and surveillance measures

- all facilities and installations of the final geological repository, above and below ground, including the waste disposal area.

Safeguards applied (in addition to Model 2):

- operational phase
  - inspector access to all underground facilities (including the waste disposal area) on a random basis or
  - unrestricted inspector access to all underground facilities (including waste disposal area).

## 4.3 Safeguards Elements

### 4.3.1 Requirements

The final repository is a purely conventionally equipped disposal facility. Only conventional hoisting and transport installations are envisaged. All the nuclear material is contained in canisters in such a manner as to be handled conventionally. Facilities for handling, investigating or otherwise treating open irradiated material, such as e.g. hot cells, radiochemistry etc., are not envisaged. It is not technically possible to verify the contents of the FDP's in the final repository since all necessary preconditions are lacking. Reception control procedures of the package consist of recording, measuring the dose rate and a wipe test. All verifications over and above this with respect to form, quantity and composition of the nuclear material in the FDP, required on the basis of national and international safeguards regulations, must therefore be implemented before the FDP's are delivered to the final repository, i.e. in the conditioning facility.

A decisive element in designing the safeguards system is the fact that the FDP's neither change their form nor their composition nor their external appearance in the final repository. Solely changes in location of the nuclear material are implemented, in accordance with the precisely predetermined sequence model. The objective of safeguards is thus to ensure that the declared FDP is transported in the declared form (i.e. unaffected integrity) to the declared location and then remains there.

The following requirements are the starting point for the safeguards system:

1. The period between the last verification of an FDP in the conditioning facility and emplacement of this FDP in the final geological repository is less than the detection time required for the material so that an intermediate inventory verification is not required from the safeguards aspect.

2. A positive verification of the identity of the FDP and the integrity of its external cladding, i.e. the lost shielding, is a sufficient condition for the verification of the nuclear material contained in the FDP.

3. Continuous monitoring of the flow of packages can be dispensed with as long as the FDP remains accessible for this verification, or the inspector has access to the individual FDP's.

4. If the FDP itself is no longer accessible, or it is in areas to which the inspector does not have access, and verification by examining the identity and integrity is thus not possible, then safeguarding potential diversion paths is sufficient in order to be able to make a statement about the inventory of enclosed nuclear material.

Requirement 1 implies that the time required for transporting the FDP from the conditioning facility to the final repository and for emplacing the FDP is less than the detection period required for diverting the FDP material. No further verifications are thus required for reasons of timeliness of detection between the time of leaving the conditioning facility and the emplacement process. Transport monitoring possibly required for reasons of physical protection is not included in the safeguards concept.

Requirement 2 implies that all nuclear material data with respect to type, quantity, composition etc. required for the safeguards system have already been determined before transportation to the final repository. Verification of the nuclear material in the final repository is restricted to establishing that these previously determined data are still valid since there are no indications for a presumption to the contrary. These data are merely carried forward in the accountancy of the final repository.

According to Requirement 2, examination of the identity and integrity is sufficient to verify the nuclear material as far as safeguards are concerned. In the case of a positive result, the safeguards authority can conclude that no changes have arisen since the last verification of the material and thus that the data from the last verification are still valid. The continuity of knowledge for the period between these verifications is thus established for the safeguards authority. As long as Requirement 3 is still valid there is no need for permanent safeguards on the flow of nuclear material to maintain the continuity of the safeguards authority's knowledge.

The principle of the safeguards system is based on the examination of the accounting data and independent verification of the material. At no time is a direct independent verification possible in the final repository. As long as the FDP's are still accessible an indirect verification can be effected in accordance with Requirement 2. However, as soon as the FDP's have been emplaced and the tunnel sections backfilled a verification in this form can no longer be implemented either. The outermost covering then consists of the packing material, the surrounding salt rocks and the ends of the tunnel. Verification can now only be implemented indirectly in that the integrity of this covering is verified (Requirement 4).

The problem is how can the integrity of a backfilled or tamped tunnel, and in the post-operational phase the integrity of the whole repository, be rendered verifiable for the safeguards authority. The safeguards system requires that the safeguards authority can make a statement with a quantifiable error tolerance about the quantity of nuclear material present. The safeguards authority can only make this statement by establishing the quantities of material which have been emplaced and subsequently determining the probability with which the quantities of material could be diverted without their knowledge or subjected to an unforeseen application. This means on the one hand that the safeguards authority must monitor the potential diversion paths known to them for material backflows and on the other hand make sure that there are no further undisclosed accesses to the emplaced material, or that the material is not being used for an undeclared purpose.

Requirement 4 implies that safeguarding the potential diversion paths the requirements have basically been fulfilled for the safeguards authority to be able to make the statement necessary for the safeguards system concerning the inventory of enclosed nuclear material. This is basically a question of quantifying the completeness and effectiveness of these measures in the safeguards sense.

### 4.3.2 Material Accountancy

Material accountancy is pure item accountancy. Each FDP is both item and batch. The shipper data from the conditioning facility are taken over unaltered as data on the quantity and composition of material. Since measurements cannot be made in the case of the final disposal packages, these data are not subject to any further alterations. Apart from the possibility of exempting nuclear material from safeguards and apart from material being retransported for rework requirements, the inventory changes to be recorded only consist of additions. The emplacement process is documented by operating records.

The final repository does not display any special features with respect to material accountancy. Only the form and content of the operating records documenting the emplacement process are to be coordinated with the safeguards authority.

### 4.3.3 Containment and Surveillance Measures

#### 4.3.3.1 Seal Devices

The emplacement process is envisaged as a continuous process. As a rule, the incoming FDP's are transported below ground without delay. If a continuous emplacement process is also to be ensured in applying safeguards measures then this requires that the identity and integrity of the FDP's be verifiable in situ without expending much time. This requirement must be considered in designing the outermost shell of the FDP, the lost shielding.

Design criteria for the lost shielding are e.g.:

- homogeneous container with only one opening if possible,
- container made of one material so that it is not possible to open and reseal the containment without leaving visible traces,
- container without a protective coating of paint so that it is possible to directly verify the container walls.

Appropriate devices should be envisaged on the container so that the body and lid can be sealed together. Protective devices against mechanical stress during transport should be envisaged for the seal mechanism.

In any case the seal should be designed in a redundant manner since otherwise in case of doubt about the identity or integrity of the seal it would be necessary to retransport the package to the conditioning facility and open the FDP to reverify the material content. This redundant seal measure should be very robust with respect to all conceivable interferences. For this purpose it would be conceivable to distribute weldment sections along the perimeter across the lid seam of the container. Whereas for the primary seal, the major design criterion is the possibility of verification in situ, this criterion must possibly take second place to robustness in the back-up measure. If back-up sealing requires more time for verification then this must be considered in designing the capacity of the aboveground buffer store.

Two types of seals, paper and metal, are currently in use at the IAEA. The paper seals consist of gummed seal paper and have slits making it more difficult and time-consuming to peel off and reapply the seal without destroying it. They are designed for short-term use. Disadvantages are, however, that they are difficult to handle and are especially easily damaged during transportation of the sealed packages. Application in the final repository is possible for short-term tasks.

Metal seals (type E) consist of two metallic semi-shells which lock together under pressure in such a way that they are practically impossible to open without destroying the seal. A special seal wire is passed through two holes in one semi-shell and knotted inside the shell. By placing the second semi-shell in position the knot becomes inaccessible and the seal is thus closed. This metal seal has the advantage of being easy to handle but it can only be verified in the IAEA laboratory. Verification of the seal is thus generally delayed by several weeks. The metal seal can possibly be used as a back-up seal for the FDP's.

Seal verifiable in situ are not yet part of the standard C/S measures. However, some devices are at an advanced stage of development or testing so that their availability can be expected in a foreseeable period, such as e.g.:

- fiber optic seal
- electronic seal
- weldment seal.

In the case of the fiber-optic seals, the ends of a fiber-optic loop are joined at right angles or crossed over and enclosed by a casing. The arrangement of the individual fibers shows an unambiguous arrangement picture which can be photographed through a microscope and compared with earlier pictures or evaluated by an electronic interrogation unit.

In the case of the electronic seal, a fiber-optic loop is monitored with the aid of statistically generated light pulses and an opening of the fiber-optic loop is recorded at the VACOSS instruments specifying date and time. The seal is interrogated via an adapter box or possibly via a remote interrogation installation. The electronic seals are reusable.

In the case of weldments, there are differentiating features suitable for identity verification both in the melt configuration as well as in the side notch line of the weld. The weld can be verified in two different ways:

- by producing and measuring an impression (microscope),
- photographically.

However, the applicability of weldment seals still has to be practically tested.

4.3.3.2 Optical Sensors

Optical sensors are required to safeguard potential diversion paths for undeclared backflows of material. The following features should be observed:

- Illumination
  An emergency power supply is not envisaged for the underground facilities. An independent emergency power supply must therefore be installed for the safeguards instrumentation.

In order to possibly be able to dispense with emergency illumination it should be considered whether low-light level or infrared cameras can be used.

- Recording Intervals

  In order to be able to recognize a detection with single-frame operation, the image frequency would have to be greater than the minimum time required to pass through the camera's field of vision. Since this would have to be assumed in the range of a few minutes, a relatively high picture frequency would thus be required and a high recording capacity. The problem moreover results with this procedure that if only one, or very few, pictures are available to evaluate a process, then the process can often not be unambiguously interpreted.

Since activities generally only occur sporadically in the visual range of the camera and are of relatively short duration (transport processes), the installation of motion detectors seems to be most appropriate. These motion detectors are electronic cameras which only take pictures if the content of the field of view changes. Since the transportation of an FDP will at any rate cause a large change in the image due to its dimensions, this should probably ensure the triggering of a visual record by FDP transports.

A conceivable alternative would be permanent monitoring with TV cameras and monitors in a safeguards control room. This would however be considerably more expensive since the control room would require a permanent inspector (24 hrs.).

Film cameras do not seem suitable for use in the geological repository since image recording triggered by movement is not possible here. The high image frequency required for single-frame processes would thus involve disproportionally great expenditure for image evaluation.

Two optical safeguards systems are currently employed by the IAEA, twin Minolta cameras and psychotronic TV cameras. The twin Minolta units consist of two identical ciné cameras accommodated in a casing taking single-frame pictures at an adjustable interval. These units are frequently used to safeguard wet storage pools in LWR facilities.

The psychotronic TV cameras are only used in cases of special application since they display great reliability problems. However, a number of advanced TV camera safeguards systems are currently being developed or are at the trial stage so that it can also basically be assumed here that suitable instruments will be available in the foreseeable future.

## 4.4 Diversion Analysis

### 4.4.1. Operational Phase

#### 4.4.1.1 Model 1 (no inspector access to the underground facilities)

The simplest opportunity for a diversion exists on the transport path from the conditioning facility to the final repository. However, it would also be easy to detect due to the measures discussed. If counting, identity and integrity verification are to be regarded as very reliable measures, then a diversion after this verification would have a higher probability of remaining undetected. The safeguards authority's strategy must be to implement these measures at the last possible moment in order to make a clandestine diversion more difficult for the operator. If the inspector has access under ground than he can undertake verification there. Verifications above ground serve to prevent any FDP's whose identity or integrity cannot be established beyond doubt from being transported under ground.at all.

It must be possible to undertake reliable identity and integrity verifications indicating tamper attempts. Otherwise the operator would have the opportunity of replacing the FDP's by dummies during transportation and if this was noticed by the inspector of declaring this as a failure of the seal. Since transportation back to the conditioning facility is necessary for verification, the operator could then replace the dummy by the original FDP during transport and thus conceal his diversion attempt.

Diversion possibilities above ground before transporting the FDP's into the final repository consist in the following activities

- the diversion of FDP's without their replacement
- replacing FDP's by dummies (= FDP without nuclear material)
- clandestine opening of FDP's, removal of nuclear material.

These possibilities of diversion can be detected by:

- counting the FDP's
- identity verification of the FDP's and
- integrity verification of the containers (lost shielding).

These verifications assume that the lost shielding of the canisters is constructed in such a way that any damage to the integrity becomes apparent by inspection. It should be possible to achieve this objective with the envisaged cast container. The container is designed to have two openings each safeguarded by a seal. If the container is opened at any other place then it will have to be welded together which would be detected in an optical inspection of the container walls.

If the requirements of

- tamper-resistant seals verifiable in situ for the lid and bottom openings of the container and
- unambiguous integrity verification of the container walls by an optical inspection (it may also be

necessary to seal the protective neutron covering of the lost shielding)

for the FDP's could be fulfilled then diversion above ground can be ruled out with great reliability. The FDP's are counted and verified before being transported to the shaft. During these safeguards the

- missing FDP's
- dummies and
- clandestinely opened FDP's

would have to become apparent. The FDP's remain under optical surveillance (human oder camera surveillance) until they are transported under ground.

The diversion possibilities for FDP's transported under ground depend very largely upon the technical expenditure a potential divertor is prepared to invest in order to execute the diversion. Since there is no hot cell facility under ground which would be required to disassemble the FDP's and repack the nuclear material, in the case of a supposed diversion the nuclear material can only be transported above ground in units with at least the dimensions of an FDP. If the hoisting equipment of the shafts were safeguarded by optical instruments the transportation above ground of objects with these dimensions could be detected in any case.

#### 4.4.1.2 Model 2 (Limited Inspector Access to the Underground Facilities)

Whereas in Model 1 the inspector does not have any opportunity of verifying the flow of final disposal packages under ground, strategic points are established in Model 2 in order to safeguard the flow of packages up to the emplacement location. Since underground transport extends for several kilometers continuous monitoring entails a good deal of expenditure. Those points are safeguarded at which the packages are reloaded from one means of transport to another since the possibility of substituting dummies for the FDP's would be most easily achieved here. These points are (cf. Fig. 4-2)

- SP-A strategic point pit bottom at Shaft 2 (not in the Figure)
- SP-B junction of access gallery - emplacement connection drift
- SP-C junction of emplacement connection drift - emplacement tunnel.

A reverification of the FDP's at the emplacement location could be regarded as an alternative or a supplementary measure. This verification can either be undertaken personally, i.e. by the inspector, or by a tamper-resistant recording C/S instrumentation.

The credibility of the safeguards concept can be significantly increased by underground optical safeguards instrumentation. These devices ensure that the existing transport paths cannot be used for a diversion. The cameras at points B are especially significant. They safeguard that the in-coming final disposal packages are actually reloaded onto the emplacement machine and transported to the emplacement connection drift. Furthermore, this camera can also monitor the sealing of the emplacement fields already backfilled. The cameras at points C in the emplacement connection drift ensure that no connection is made from the emplacement connection drift to the exploratory level above it into which the FDP's could then be brought, but rather that they are actually transported into the emplacement tunnels. Surveillance of the emplacement tunnel itself seems to be less meaningful, firstly since at least two emplacement tunnels are always in operation and secondly since a frequent repositioning of the camera would be necessary. Diversion from the emplacement tunnel without retransportation into the emplacement connection drift seems rather implausible since there is no connection from the emplacement tunnels to the exploratory floor.

In this safeguards model it can be credibly demonstrated that the FDP's are actually transported to the emplacement

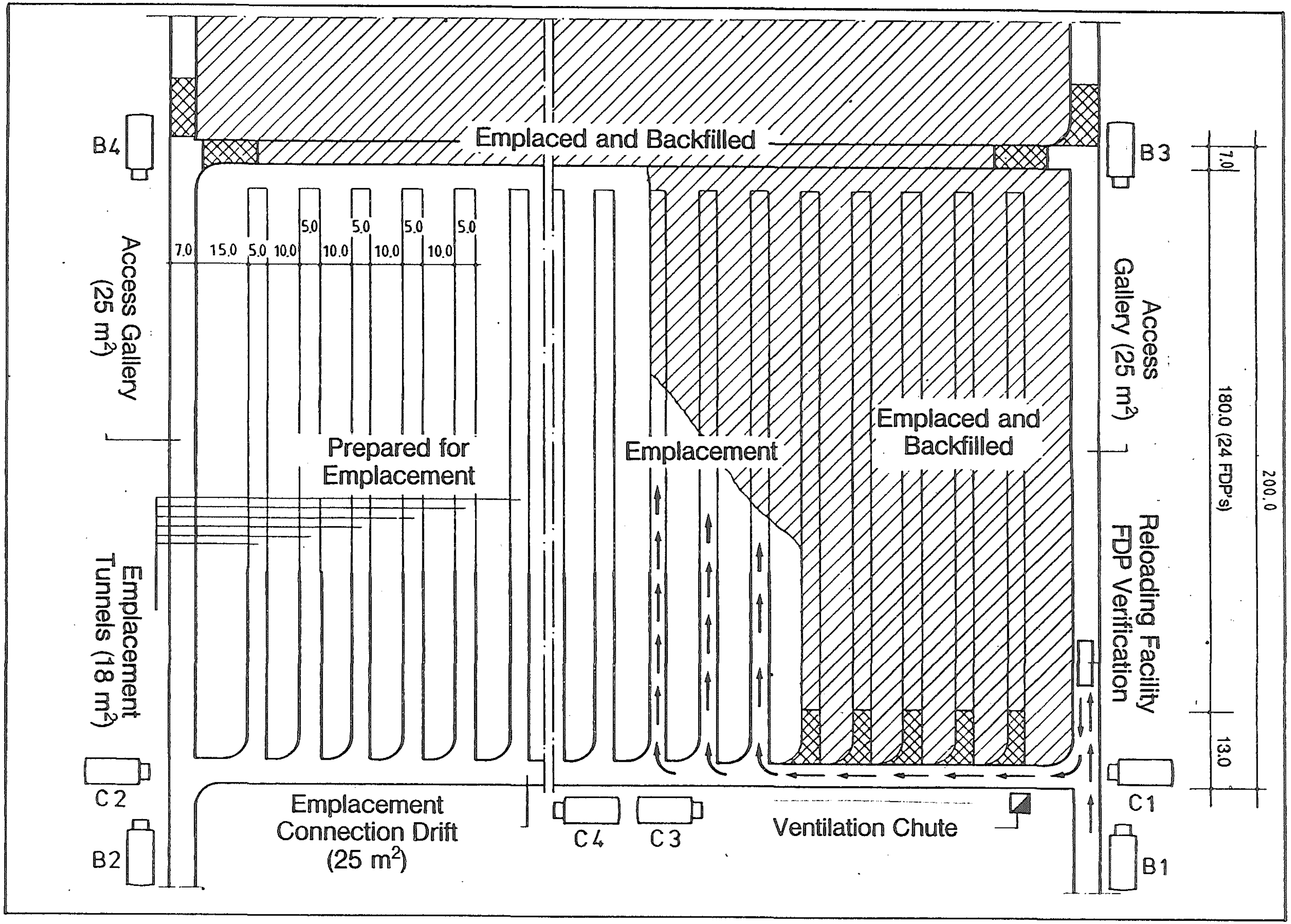


Figure 4-2: Strategic Points in the Emplacement Field

location, the emplacement tunnels are backfilled according to regulations and sealed and that the sealing of the tunnels and fields is not opened again. This requires a relocation of the monitoring cameras, at the latest when emplacement operation is taken up in a new field. This relocation makes it necessary to reverify the instrumentation.

#### 4.4.1.3 Model 3 (Unrestricted Inspector Access to All Underground Facilities)

Even if the inspector is granted limited access to strategic underground points, safeguards opportunities end when the FDP has been emplaced or the tunnel tamped. Opening up the dam again would probably be the easiest, but not the only, possibility for the operator to implement a diversion. It would be possible for him to open up additional access to the material with the equipment available below ground and thus to by-pass the dam sealing the tunnels.

If one does not rule out the possibility of the presence of an underground hot cell facility then the nuclear material from the FDP's could theoretically be repacked into any number of small innocent-looking containers and could be brought above ground e.g. disguised in the debris. The material could perhaps even be processed below ground so that only the strategic material itself without ballast need be brought above ground. The task of checking all transports of material and debris going above ground for concealed nuclear material must in the authors' opinion be regarded as unimplementable. If this diversion opportunity is to be regarded as realistic and thus to be included as a diversion strategy then appropriate safeguards should rather be applied in examining the facility design. A permanent verification of the facility design is from the present perspective the most comprehensive possibility of excluding diversions under ground. However, this requires that the inspectors have access to all underground facilities at all times. Apart from the FDP storage area, this also includes the infrastructure section (workshop, hopper, whole exploratory floor etc.) and the waste package storage area. The inspector must satisfy himself that these facilities are being used in accordance with regulations and not misappropriated for a diversion, and that there are apparently no further undeclared facilities.

### 4.4.2 Post-Operational Phase

The essential aspect of safeguards in the post-operational phase is firstly that the authority satisfies itself that the repository has been sealed according to regulations. This also means that the post-operational phase only begins when both FDP emplacement as well as waste package emplacement has been completed. A diversion in the post-operational phase could be effected by:

1. sinking a purpose-built shaft directly to the enclosed FDP's with the aim of bringing individual or several FDP's above ground, or
2. by clandestinely opening new access to the emplaced material from a considerable distance.

The diversion possibility mentioned in 1 must be classified as at least technically very difficult. Suggested safeguards would be to monitor the site by inspections.

The second possibility of uncovering new access from a considerable distance would be by far the most expensive and time-consuming diversion possibility. It would involve new shafts being driven. The extent to which this could be implemented in practice at all would still have to be examined.

### 4.4.3 Evaluation of Effectiveness

Model 1 proceeds from the following assumptions which are accepted as given facts for the safeguards model and not verified further:

- There are no hot cell facilities below ground.
- There is no other connection from the underground facilities to the surface except via the safeguarded shafts.
- Misappropriation of nuclear material is ruled out within the underground facilities (internal diversion) since EURATOM has access.

In a purely technical consideration, the weakness of this safeguards model is quite clearly to be found in the fact that the complex "clandestine facilities" is by definition not included. It must be remembered that emplacement operation only represents a small fraction of the total handling activities in the final repository. New fields are continually being opened up parallel to emplacement both in the FDP storage area as well as in the waste package area. This necessarily involves extensive debris and material transports. The principle of transparency would not be applicable here either since the underground activities are not transparent for the inspector who can only safeguard at the surface. Design verification before beginning emplacement operation also only provides limited evidence since the extension of the underground facilities is permanently modified.

However, in an overall evaluation of this safeguards model this technical deficit must be seen in relation to other parameters. These other parameters are e.g. quantity, recoverability and strategic value of the emplaced material. The attractiveness of this material for a potential divertor must be compared with the technical and organizational effort required to implement a clandestine diversion. The technical feasibility of a diversion with the aid of clandestine underground facilities can undoubtedly not be basically ruled out. The chances of being able to successfully implement a clandestine diversion in this way must, however, be regarded as extremely remote, especially with respect to the supranational character of national safeguards (EURATOM).

In comparison to Model 1, Model 2 does not provide any improvements in principle, but rather, even if to a considerable extent, only improvements in degree. The existence of clandestine facilities via which a diversion could take place cannot be reliably ruled out in this case either. In this model diversion would be possible by opening up access to the already emplaced FDP's from the workshop area or the waste store.

In Model 3 the inspector is thus practically granted the possibility of design reverification at all times. In this case the danger of detection of undeclared facilities is considerably increased for a potential divertor but nevertheless this possibility is still not reliably ruled out.

The technical feasibility of a diversion has been considered in safeguards models to date. In any case, underground facilities would be required for a diversion in which the FDP's could be disassembled and the nuclear material repacked in unsuspicious packages which could then be brought to the surface disguised in the debris or in items of equipment. The establishment of an underground reprocessing facility would involve considerably more expenditure and an even greater risk of detection. As far as can be foreseen to date there are no technical safeguards which can rule out these diversion possibilities in principle. These diversion possibilities have to be classified as technically feasible, even if requiring immense expenditure.

The diversion scenarios discussed for the post-operational phase would in principle also be applicable in the operational phase. However, they involve greater expenditure and a higher detection risk.

In order to sink a purpose-built borehole, the minimum time would first have to be determined required to sink the borehole, transport the FDP(s) to the surface and cover the traces. These time requirements determine the inspection interval for safeguards.

Site inspections are envisaged as safeguards. Since sinking an appropriate borehole would require extensive technical preparations it is practically certain that these signs would be recognized during a site inspection.

The clandestine sinking of new shafts to recover the emplaced material would probably require even more effort. A further difficulty is encountered in determining the area to be subjected to safeguards. If this diversion possibility is to be considered as realistic so that appropriate safeguards precautions would have to be taken then site inspections would also probably be a suitable measure in this case.

In all models the question of how the effectiveness of containment safeguards in the operational phase or monitoring the site in the post operational phase can be quantified emerges as the principal difficulty. This problem cannot be solved by an exclusively technical approach since in the final repository every safeguards measure can in principle be evaded by increasing the diversion efforts. No safeguards measure can thus be classified as reliable from a technical aspect.

## 4.5 Evaluation of the Effectiveness and Analysis of the Vulnerability of the Safeguards System

### 4.5.1 Phase 1 - Aboveground Transport

This phase begins as the FDP's leave the conditioning plant and terminates when these FDP's are transported via the shaft in the final repository. It therefore comprises the whole time the FDP's spend above ground. Possible diversion strategies during the aboveground transport phase of the FDP's are:

- diversion of the FDP without replacement
- replacing the FDP by a dummy and
- clandestine opening of the FDP and removal of nuclear material.

The envisaged safeguards (see Table: 4-3) for this phase are identical for all three safeguards models. They consist of counting the FDP's, verifying the identity and integrity. The identity is verified on the basis of tamper-proof differentiation features on the outermost cladding of the FDP. This task is taken over by the sealing device with which the body, lid and bottom of the lost shielding are sealed together. So that the seal can be verified immediately before transporting the FDP under ground it must be verifiable on site by inspection or interrogation without time-consuming evaluation processes. This task can for example be fulfilled by an electronic seal.

All FDP's leaving the conditioning plant must pass through this verification procedure within a certain time limit. This ensures the completeness of safeguards in the transport phase at the surface. After verifying the seals, the FDP's are transported into the hoisting cage without further delay. Whether further safeguards against a potential exchange of the FDP's during this period will have to be undertaken depends on the concrete structural features of the surface facilities, these not being currently known. If e.g. it cannot be reliably ruled out that the FDP's could be transported back to the unloading facility without the inspector's knowledge and there replaced by dummies, then this period can be bridged by labelling the FDP's with paper seals.

The envisaged safeguards (identity and integrity verification) should not raise any considerable problems with respect to their reliability and unambiguity since they can both be repeated as often as required. Only the seal could possibly be damaged during transport procedures. Diversified redundancy is envisaged as a supplementary procedure, i.e. for example a robust mechanical seal in parallel to an electronic seal. If in exceptional cases it is no longer possible to clearly identify the FDP's, e.g. due to transport damage to the seal, then at this phase the possibility still remains of bringing these FDP's back to the conditioning plant and measuring them again. Retransport after transportation accidents would probably be necessary in any case.

If the completeness of the safeguards can be taken as given then the following parameters remain which could impair effectiveness, namely tamper-resistance and the possibility of outwitting the safeguards. These parameters can, however, be influenced by the design of the outermost cladding of the FDP's and by the choice of seal(s). No significant difficulties are envisaged on the basis of the current state of the art. Sufficient safeguards can thus be ensured, in the author's opinion, during the phase of transporting the FDP's above ground.

4.5.2 Phase 2 - Transport Under Ground

This phase begins with the transportation of the FDP's through the shaft and finishes when the tunnel section already occupied by FDP's are filled in. It thus comprises the whole period when the FDP is accessible for direct monitoring or verification of the identity or integrity of its cladding under ground.

Two steps are required to divert nuclear material during this phase. First of all, the FDP's would have to be withdrawn from the normal operational sequence, i.e. smuggled out of the emplacement process and thus out of the reach of further safeguards. This can in principle be achieved with the same diversion strategies as during the aboveground transportation phase (see Table 4-4).

The second step consists of subjecting the clandestinely removed FDP's to an undeclared application (see Table 4-5). This means that the FDP's must be further processed in a suitable facility. The decisive criterion for safeguards is whether the operator clandestinely modifies the plant design so that the FDP's can be transported to the further processing facility without being noticed or whether he undertakes this diversion via the existing transport paths. In the case of a diversion without modifying the plant design, the FDP's will have to be retransported via Shaft 1 or Shaft 2.

If one assumes that it is also possible to modify the facility design in order to implement a diversion then three alternatives would theoretically result:

1. The establishment of a clandestine hot cell facility under ground to disassemble the FDP's and repack the nuclear material into small, innocent-looking containers which can then be brought to the surface unnoticed in the material or debris transports.

2. Construction of a clandestine underground facility to separate the strategic material from the FDP's.

3. Creation of an additional clandestine connection to the surface via which whole FDP's or repacked smaller quantities of material can be transported unnoticed.

4.5.2.1 Model 1

In Safeguards Model 1 it is assumed that clandestine design modifications can be ruled out. Since in this model the inspector has no underground access, no safeguards can be applied underground either. The operator could thus implement the first step in a diversion, i.e. clandestinely removing the FDP's from the normal emplacement process, without being noticed. However, in order to complete the diversion the FDP's would have to be retransported to the surface via either Shaft 1 or 2. Diversion strategies and safeguards are compiled in Tables 4-4 and 4-5. Optical monitoring of the transport facilities is envisaged as a safeguard against retransport. Unloading objects from the transport facilities with at least the dimensions of an FDP would be the anomaly to be observed indicating a diversion. However, for Shaft 2 it must be ensured that

- the retransportation of objects of these dimensions actually means an anomaly, i.e. does not occur in the normal operating sequence and
- this event can be optically unambiguously identified.

Apart from the dimensions, the weight of the object can also indicate an anomaly since in normal operation no retransportation is to be expected in the range of more than 25 t (based on the removal of debris or other normal operational transports to the surface). However, the direction and load of the hoisting equipment must be recorded in a tamper-proof manner which could be achieved via the consumption of electricity of the winding engine.

This measure is not required for Shaft 1 since an FDP does not geometrically fit into the hoisting cage. Neither is there any device at Shaft 1 to balance the elongation of the rope of several meters /4-4/ which would occur if an FDP were attached to the hoisting cage. It can be assumed that this type of extensive action would be reliably optically detected by the safeguards devices.

In order to be able to make concrete statements about the reliability and possibilities of outwitting the safeguards, concrete data about the structural form of the transport facilities and buildings are necessary in order to then be able to determine e.g. where the camera should be installed, the possibility of unintentionally impairing or blocking the field of vision, possibilities of deception by dazzling or turning off the illumination etc.

However, in the authors' opinion this safeguards task should be categorized as capable of being satisfactorily solved. Roughly comparable tasks such as fuel element handling in LWR wet storage pools have already been satisfactorily solved for years in common practice by optical safeguarding. Providing that there is no need to consider an undeclared modification to the facility design, effective safeguarding should be realizable with Model 1 in this phase. If this presumption cannot be made then Model 1 does not provide complete safeguarding of all diversion possibilities and thus would be unacceptable to the safeguards authorities.

### 4.5.2.2 Model 2

In Model 2 the inspector has access to strategic points below ground and is thus also in a position to monitor the nuclear material flow under ground. Over and above Model 1, Model 2 attempts to detect the first step in a diversion, namely the clandestine removal of FDP's from the normal operational sequence.

In the first place, optical monitoring of the reloading process is envisaged at all points where the continuous transport is interrupted due to reloading to a different means of transport, since at these points it would be easiest to divert the FDP without replacement or to substitute a dummy. The first of these points (strategic point A) is when unloading the plateau transporter from the hoisting cage at the filling station of Shaft 2. Safeguards will ensure that the FDP transported under ground is also actually unloaded into the emplacement floor. The second safeguards point (strategic point B) is the reloading facility from the access gallery to the emplacement connection drift. This camera observes the reloading of the FDP's from the plateau transporter to the emplacement machine. Further safeguards devices are envisaged in the emplacement connection drift itself (strategic point C). It can thus be observed whether the FDP's are transported to the envisaged emplacement gallery by the emplacement machine and also remain there. See Fig. 4-2 for the position of strategic points B and C.

Due to the long underground transportation paths (several kilometers), uninterrupted transport monitoring would be unjustifiably expensive. Since transportation only occurs sporadically and the FDP's can only be within the visual range of the individual cameras for a very short period, these safeguards devices should be equipped with motion detectors. All movements within the visual range of the camera can thus be completely recorded without having to envisage unnecessary frame storage capacity, and thus also frame verification expenditure, for the periods with no movement. If the date and time of the event are recorded with the movement then delays in transportation which would be required to manipulate the FDP's or replace them in the zones not directly safeguarded could be detected. This thus provides a high degree of reliability to ensure that the FDP's transported below ground are brought into the envisaged emplacement tunnels without manipulation.

As a supplementary or alternative measure a reverification of the FDP's deposited in the emplacement tunnel can be undertaken by the inspector. The cameras at the strategic points B and C furthermore ensure that the FDP's deposited in the emplacement tunnel are not subsequently removed again. This process would be recorded by the cameras. A technical problem still to be studied in detail is the tamper-proof transmission of the frames to a safeguards control room which could most appropriately be situated above ground.

Over and above the possibilities of Model 1, Model 2 can thus ensure that the envisaged operational sequence is observed and no FDP's are clandestinely removed. The primary measure is optical safeguards at the strategic points A, B and C. FDP's deposited in the emplacement tunnel can be reverified by the inspector as a substitute measure in case of camera failure and on a random basis to reduce the residual risk of manipulating FDP's in the unsafeguarded intermediate areas. This should not cause delays in the operational sequence since there is usually a shift loss by breaks between emplacement and backfilling. In this phase Model 2 should thus provide sufficient reliability that the first step in a diversion, clandestinely removing FDP's from the normal operating sequence, can be detected.

With respect to the second step necessary for a successful diversion, namely clandestine transportation of the FDP's to the further processing facilities, Model 2 is identical to Model 1 (see also Tables 4-4 and 4-5). This safeguard thus represents an additional barrier for a potential divertor.

#### 4.5.2.3 Model 3

Model 3 goes beyond Model 2 by envisaging a further barrier for the second step required in a diversion, transporting the FDP to the further processing facilities after clandestine removal. This barrier consists in the right granted to the inspectors of reverifying the plant design at all times. This measure is admittedly primarily aimed at the next phase but it already functions as an additional safeguard in Phase 2. It must be noted that the safeguards measures for Step 1 and Step 2 are not to be regarded alternatively but rather cumulatively (see Tables 4-4 and 4-5). In addition to the safeguards outlined in Step 1, the safeguards in Step 2 must also be overcome for a successful diversion.

### 4.5.3 Phase 3 - Storage During the Operational Period of the Final Repository

This phase comprises the period after packing the individual tunnel sections occupied by FDP's until backfilling of the final repository shafts, that is to say the period in which mining activities are being implemented in the vicinity of the emplaced FDP's.

Two steps are also required at this stage for a successful diversion. Since the FDP's are already stowed at this phase, the first step consists of making the FDP's accessible by uncovering an entrance. The second step is identical to the second step of the previous phase. Strategies and measures for this phase are shown for all three safeguards models in Tables 4-6 and 4-7. The uncovered FDP's must be transported to the processing facilities. However, in contrast to the second phase, here in the third phase the first diversion step is already possible by an undeclared design modification. The uncovering of an entrance to the already backfilled or tamped emplacement tunnels is either possible directly by reversing the emplacement process, i.e. opening up these tunnels starting from the available galleries, or indirectly by creating new clandestine entrances from non-safeguarded areas, e.g. hopper, workshop, exploratory level or even the waste storage area.

4.5.3.1 Model 1

No new safeguards are envisaged in Model 1 for this phase. The same assumptions are valid as for the previous phase, i.e. that undeclared alterations to the facility design are ruled out. A diversion would be detected when retransporting the FDP via the shaft facilities.

4.5.3.2 Model 2

Model 2 already begins at the first step in a diversion, uncovering access to the FDP's. The range of effectiveness of the safeguards envisaged for Phase 2 is thus extended. The integrity of the tunnel closures and material recovery via this path can be monitored by the safeguards devices installed at the strategic points. Human verification of the tunnel closures by inspection is envisaged as a substitute measure in the case of camera failure and as supportive measure on a random basis.

The diversion strategy for the first step required in a diversion can be detected by these safeguards. The uncovering of a clandestine access by by-passing the sealing devices cannot be detected by the safeguards envisaged in Model 2. Further safeguards are therefore discussed in Model 3 as a protection against this diversion strategy.

4.5.3.3 Model 3

Model 3 envisages permanent design reverification on a random basis for all underground facilities. In order to conceal the uncovering of the FDP's a potential divertor will make this attempt from areas to which the inspector has no access. The most effective method of preventing this diversion strategy is thus to grant the inspectors unrestricted access to all facilities of the final geological repository. The inspectors must be able to satisfy themselves that there are no undeclared connections or facilities within the geological repository and that only emplacement activities are being implemented.

Permanent design reverification is a safeguard which applies to both the first and the second diversion step. In the authors' opinion it thus represents the most comprehensive safeguard against undeclared activities, nevertheless its effectiveness is difficult to quantify.

### 4.5.4 Phase 4 - Post-Operational Phase of the Final Repository

This phase begins with the closure of the geological repository by backfilling the shafts and lasts as long as the material is subject to safeguards.

In this phase diversions can be implemented by:

- sinking a purpose-built borehole or shaft to recover one or a few FDP's or
- reopening the repository, e.g. from a considerable distance, to divert larger quantities.

Periodic inspections of the site to verify the integrity of the sealed geological repository are envisaged as safeguards.

Drilling or sinking activities at the repository site could certainly be detected during the site inspections. The inspection intervals would therefore only have to be shorter than the necessary diversion period, i.e. the time required to sink the borehole or shaft, recover the FDP's and cover the traces. Whether reopening of the repository can be detected by site inspections depends on the distance from which it is reopened. Even if the effectiveness of this safeguard is difficult to quantify, site surveillance represents in the authors' opinion the most suitable safeguard for verifying the integrity of the shutdown repository.

## Phase 1: Transport Above Ground

### Conditioning Facility Exit – Beginning of Shaft Transportation

| Diversion Strategy | Safeguards Measures<br>Model 1 Model 2 Model 3 |
|---|---|
| Diversion of Whole FDP's | Counting the FDP's |
| Replacement by Dummy FDP | Seal Verification and FDP Integrity Verification Upon Entering the MBA, Subsequent Optical Monitoring |
| Removal of NM from the FDP | FDP Integrity Verification Upon Entering the MBA, Subsequent Optical Monitoring |

Effectiveness: Acceptable

Table 4-3: Safeguards in Phase 1 – Transport Above Ground

## Phase 2: Transport Under Ground

### Beginning Shaft Transportation – Backfilling on Site

| Diversion Strategy | Safeguards Measures: Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| **1st Step:** Clandestine Removal of FDP or NM from the Operational Sequence | | | |
| a) Diversion of Whole FDP's | — | Counting the FDP's | |
| b) Replacement of FDP by Dummy<br>c) Removal of NM from FDP | — | Transport Monitoring with TV Camera at SP A, B and C<br>*and/or*<br>Random Seal Verification and FDP Integrity Verification before Emplacement<br>*and*<br>Monitoring Potential Diversion Paths with TV Camera at SP's B and C | |

Table 4-4: Safeguards in Phase 2 – 1st Diversion Step

## Phase 2: Transport Under Ground

### Beginning of Shaft Transportation – Backfilling on Site

| Diversion Strategy | Safeguards Measures Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| **2nd Step:**<br>a) Retransportation of FDP's to the Surface Disguised as Debris or Material | TV Camera at Both Shafts, Tachograph and Load Recorder at the Winding Engine of Shaft 2 (25 t-Criterion) | | |
| b) Underground HC Facility Repacking the NM in Unsuspicious Containers, Retransportation through Existing Facility<br>c) Underground RP Facility<br>d) Clandestine Connection to the Surface | —— | —— | Permanent Design Reverification of all Underground Facilities, Verification for Undeclared Design and Activity Alterations |

Effectiveness: Acceptable since FDP's Still Accessible

Table 4-5: Safeguards in Phase 2 – 2nd Diversion Step

## Phase 3: Storage During the Operational Period
## Backfilling the FDP's – Closing the Geological Repository
## (Backfilling the Shafts)

<table>
<tr><th rowspan="2">Diversion<br>Strategy</th><th colspan="3">Safeguards Measures</th></tr>
<tr><th>Model 1</th><th>Model 2</th><th>Model 3</th></tr>
<tr><td>1st Step:<br>Access to Emplaced FDP's</td><td></td><td></td><td></td></tr>
<tr><td>a) Uncovering and Diverting FDP's via Existing Transport Paths</td><td>—</td><td colspan="2">TV Cameras at SP B (Tunnel Closure) and SP C (Emplacement Connection Drift)<br><br>Random Verification of Tunnel Closures by Inspectors</td></tr>
<tr><td>b) Clandestine Entrance by By-Passing Tunnel Sealing via Exploratory Floor, Waste Store etc.</td><td>—</td><td>—</td><td>Permanent Design Reverification of All Underground Facilities</td></tr>
</table>

Table 4-6: Safeguards in Phase 3 – 1st Diversion Step

**Phase 3: Storage During the Operational Period**
**Pneumatically Packing the FDP's – Closing the Geological Repository (Backfilling the Shafts)**

| Diversion Strategy | Safeguards Measures Model 1 | Safeguards Measures Model 2 | Safeguards Measures Model 3 |
|---|---|---|---|
| **2nd Step:** | | | |
| a) Retransportation of FDP's to the Surface Disguised as Debris or Material | TV Camera at Both Shafts, Tachograph and Load Recorder at the Winding Engine of Shaft 2 | | |
| b) Underground HC Facility Repacking the NM into Unsuspicious Containers, Retransportation through Existing Shaft Facility<br>c) Underground RP Facility<br>d) Clandestine Connection to the Surface | —— | —— | Permanent Design Reverification of all Underground Facilities<br><br>Verification for Undeclared Design Modifications and Changes in Facility Operation |

Effectiveness: Unsolved Problems

Table 4-7: Safeguards in Phase 3 – 2nd Diversion Step

## Phase 4: Post-Operational Phase after Backfilling the Shafts

| Diversion Strategy | Safeguards Measures<br>Model 1 Model 2 Model 3 |
|---|---|
| Purpose-Built Borehole or Sinking a Shaft to Recover Individual FDP's<br><br>Reopening the Repository from a Considerable Distance to Recover a Number of FDP's | Optical Surveillance of the Site by Periodic Inspections |

Effectiveness: Open Problems

Table 4-8: Safeguards During the Post-Operational Phase of the Final Repository

## 4.6 Resulting Problem Definition

The basic problem to be quantified in applying C/S measures is the probability with which a diversion can be detected by these safeguards. In contrast to material accountancy, there is not yet any fully developed method in applying C/S safeguards for determining MUF values (Material Unaccounted For). In practice this problem is avoided by ensuring that materials safeguarded by C/S measures are also in principle directly accessible by measurements and the safeguards authorities reserve this option. Since this option is no longer available for the final repository, quantification of the effectiveness of C/S safeguards takes on particular significance.

The weak point which has been identified in safeguarding the final repository is the limited possibility of safeguarding the integrity of a backfilled and sealed tunnel against tamper attempts through clandestinely driven undeclared entrances. Containment safeguards satisfying the demands of completeness cannot be implemented for a tunnel. The emplaced material can therefore not be sufficiently safeguarded in the mathematical sense. No measures are currently known or envisaged which could ensure sufficient safeguarding. We are indeed convinced that with permanent design reverification a diversion by means of clandestine, undeclared entrances or facilities is practically impossible to implement, nevertheless this cannot be ruled out in the sense of a mathematically logical proof nor can its detection probability be determined. Precisely this is an indispensable requirement for the safeguards system.

The major problem with respect to the safeguards concept for the final repository is that as soon as the material is emplaced safeguards can only be reinforced by C/S measures. The option of direct verification is no longer technically possible. Furthermore, the envisaged C/S measures cannot be objectively quantified with respect to their completeness and thus their effectiveness. Thus the requirements for an applicable safeguards concept required by the safeguards authorities cannot be fulfilled, judged by current practice.

# 5 SOLUTIONAL APPROACHES

## 5.1 Modifications to the Existing IAEA Safeguards Philosophy

### 5.1.1 Relativizing Numerical Detection Goals

The objective of the safeguards to be applied by the IAEA within the framework of the Verification Agreement is defined in Art. 28 VA:

> "The objective of the safeguards procedures set forth in this Agreement is the timely detection of the diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown and deterrence of such diversion by the risk of early detection."

In order to create a planning and evaluation basis for applying safeguards and in order to be able to make the declaration required in Article 30 VA on the technical conclusion of verifications, the IAEA considers it necessary to quantify these objectives. This is achieved by setting up numerical detection goals. These are:

- significant quantity
- detection time
- probability of detection and
- probability of false alarms.

The values currently set up for these detection goals have admittedly only been provisionally accepted, however they can de facto only be questioned if they can be replaced by better alternatives from the IAEA's point of view.

The definition of quantitative goals, even if they are not to be mechanically applied but rather only as guidelines, leads inevitably to the measures envisaged in a safeguards concept having to be quantifiable with respect to the degree of achieving their objective or, (more or less subjectively) quantified. In this technically quantitative approach the planning and evaluation of safeguards is implemented under the aspect of the numerical contribution they could make to the definitions of the goals.

The IAEA is admittedly aware that the quantified detection goals cannot be applied as rigid definitions and thus derives inspection goals from the detection goals where technical feasibility and facility-specific features are included in their determination, nevertheless the principle of a quantified safeguards model as such is not questioned. The measurable variable of detection probability is the central parameter for the IAEA to which safeguards planning, application of funds and evaluation of effectiveness are oriented.

Since there is currently no procedure by means of which the detection probability in applying C/S measures can be quantified safeguards models which are largely or, as in the final repository, almost exclusively based on C/S measures cannot be objectively planned by this approach nor their effectiveness calculated. This leads to them being classified by the IAEA as unacceptable. This fact has also been identified as the basic problem for the safeguards concept of the final repository.

This can be regarded as the starting point for a fundamental criticism. The basically plausible procedure of creating an objectifiable planning basis by numerical definition of goals cannot be rigorously realized in practice. As long as on the one hand C/S measures play, and indeed must play, an important role in safeguards practice, but on the other hand are not quantifiable or only by subjective evaluation, this will lead to a distortion of the planning data which then casts doubt upon the aim of an objectifiable planning basis. The task would consist of upgrading the IAEA's safeguards philosophy by developing alternative planning and evaluation processes in such a way that attributes of effectiveness and credibility could also be applied to safeguards concepts without objectively quantifiable detection probability. That this can be implemented, at least for individual cases, on the basis of a consensus is a prerequisite for the applicability of the suggested Safeguards Model 3. A consensus would have to be achieved with the IAEA concerning the evaluation of the envisaged possibility of permanent design reverification which apparently represents a considerable obstacle to diversion but whose effectiveness can in the last analysis not be verified.

### 5.1.2 Safeguarding of the Fissionable Material FLow

In signing the NP Treaty on November 28, 1969 the Government of the Federal Republic of Germany declared that it

- assumed that the agreements described in Article III of the NP Treaty between the IAEA and the European Atomic Energy Community were concluded on the basis of the verification principle and that verification would be implemented in such a manner that the political, scientific, economic and technical tasks of EURATOM would not be impaired (Item 13 of the Declaration),

- insisted that the safeguards only be applied to source and special fissionable material and in accordance with the principle of an effective safeguarding of the flow of fissionable material at certain strategic points (Item 14 of the Declaration).

It further declared that it only intended to ratify the NP Treaty if an agreement corresponding to Article III of the NP Treaty between EURATOM and IAEA were concluded fulfilling in form and content the requirements of the above mentioned Items in its Declaration (Item 17 of the Declaration).

These principles drawn up jointly with other EURATOM states are laid down in the Verification Agreement and have determined the position of the Federal Government to date.

Among the considerations for the Verification Agreement it is mentioned that

> "the Agency . . . has the responsibility to assure the international community that effective safeguards are being applied under the Treaty".

In Articles 1 and 3 of the VA

- the States of the Community undertake, in accordance with the terms of this Agreement, to accept safeguards on all source or special fissionable material for the purpose of verifying that no diversion has taken place (Article 1) and

- the Community undertakes to co-operate with the Agency, in accordance with the terms of this Agreement, with a view to ascertaining that such source and special fissionable material is not diverted to nuclear weapons or other nuclear explosive devices.

In a strict interpretation of the Verification Agreement it could be argued that since safeguards only refer to the material and not to the facilities that the consideration of diversion scenarios requiring a clandestine alteration to the plant design, such as internal diversion or diversion via clandestine accesses, need not be taken into consideration. Sufficient safeguards could thus be ensured by Models 1 or 2.

As long as there is at least in principle the possibility of satisfying oneself positively of the presence of the material by direct monitoring, the argument of safeguarding the flow of fissionable material at strategic points can be put forward. Since this flow monitoring is no longer possible in the final repository - the FDP's and thus the fissionable material being no longer accessible after backfilling - there is no longer any basis for arguing that safeguards should be restricted to the material itself and diversion scenarios requiring clandestine alterations to the facility need not be considered.

However, effective safeguards on the basis of monitoring the flow of fissionable material at the strategic points can no longer be technically implemented in the final repository so that additional agreements could be made in order to grant the IAEA an equally effective safeguards possibility. However, this type of agreement, which would undoubtedly be compatible with the spirit of the Verification Agreement, would involve legal questions which would be difficult to solve.

### 5.1.3 Releasing Fissionable Material from Safeguards

The basis for terminating safeguards is laid down in Article 11 of the VA: "Safeguards under this Agreement shall terminate upon determination by the Community and the Agency that the material has been consumed, or has been diluted in such a way that it is no longer usable for any nuclear activity relevant from the point of view of safeguards, or has become practically irrecoverable."

These criteria are not fulfilled by the FDP's. The nuclear material in the FDP's is neither diluted nor consumed in such a manner that it is no longer usable for any nuclear activity. The only approach would be the argument that due to the type of emplacement the FDP's are practically irrecoverable. If at all, this argumentation can only be applied to the post-operational phase of the repository, i.e. when all tunnels and shafts have been backfilled and the transport facilities decommissioned. During the operational phase of the repository the emplaced material cannot be classified as irrecoverable since all the equipment necessary to recover the already emplaced FDP's from below ground is available there.

Even if the irrecoverability of the FDP's could be assumed for the post-operational phase this would not improve the safeguardability of the repository during the operational phase, although due to the rise in rock temperature a diversion already becomes more difficult in the operational phase.

Even in the post-operational phase recoverability cannot be classified as technically impossible in principle. Recoverability must rather be regarded as a question of the technical expenditure to be employed. In view of the attractiveness of the emplaced material it cannot be assumed that the safeguards authority would be prepared to classify the material as irrecoverable in the post-operational phase and thus release it from safeguards.

The criteria of Article 35 of the VA are rather to be applied. . . . Where the conditions set forth in Article 11 are not met, but the Community considers that the recovery of nuclear material subject to safeguards under this Agreement from residues is not for the time being practicable or desirable, the Agency and the Community shall consult on the appropriate safeguards measures to be applied.

A statement on what the IAEA regards as appropriate safeguards cannot be currently made.

By way of summary it can be said that in all probability a final release of the material from safeguards will not be possible for the post-operational phase either. The Agreement envisages a mutual agreement on suitable measures for this case. The attitude of the safeguards authorities to these measures still has to be sounded.

### 5.1.4 Considerations of Deterrence

The aim of safeguards is laid down in Article 28 of the VA:

> "The objective . . . is the timely detection of diversion of significant quantities of nuclear material . . . and deterrence of such diversion by the risk of early detection."

The degree of deterrence is the result of weighing the consequences of detection against the advantages of a diversion. The concept of risk can be defined as the product of the probability of an event occurring and the consequences of this event. Of these two variables only the probability of occurrence ( = probability of detecting a diversion) is considered by the IAEA due to their purely technical approach in which the probability of detecting a diversion is the central value.

The second component of the risk concept, the consequences of a detected diversion, contains a large number of variables which cannot or only with difficulty, be quantified. No approaches are currently available which would make such a quantification possible. A starting point here would be granting a safeguards credit corresponding to a state's degree of vulnerability to sanctions. In the case of the Federal Republic of Germany for example, as a country poor in natural resources and strongly export-oriented, the vulnerability to sanctions and thus the extent of the consequences of detection would be very great. Taking these factors into consideration, even with a low technical probability of detection a high detection risk would result for the Federal Republic of Germany. However, it is extremely unlikely that the IAEA will accept this modification in attitude in the short term.

## 5.2 Further and Possibly Re-Development of Safeguards Elements

During the operational phase the problem consists of providing a quantifiable certainty by suitable measures on the part of the safeguards authority that the emplaced material is still present. This quantification is, strictly speaking, only possible for accountancy measures. No methods have yet been developed for numerically determining the effectiveness of C/S measures. The errors involved in C/S verification cannot be precisely specified. This problem can generally be ameliorated in other facilities in that material verification is basically implemented by accountancy measures and C/S measures are only employed for sub-quantities of material and for limited periods as back-up measures. These restrictions (limitation to sub-quantities and limited periods) cannot apply to the final repository. Safeguards would only be possible with purely a C/S concept and, as already mentioned, there is no contractual or methodological basis for this.

This means, even presuming that safeguards elements could be redeveloped or further refined and thus C/S-supported monitoring of the emplaced material were possible, it could only be included in the safeguards system as a supplementary measure. This alone does not represent a basic solution to the problem in hand. Even assuming that new safeguards elements were successfully developed, considerable efforts would still be required to further develop the theory on which the safeguards system is based in order to incorporate these new elements in the safeguards system as essential measures. The development of new safeguards elements would thus only be the first step in solving the safeguards problem.

The backfitting problem must also be seen in this context. As long as there is a possibility of measuring the material in the fuel cycle again at successive intervals, the safeguards system can tolerate the application of C/S measures whose effectiveness is not precisely quantifiable since this uncertainty can at least be eliminated in retrospect in a measuring process. If there is no longer any possibility of subsequently eliminating C/S uncertainty by a measuring process then in order to maintain the effectiveness of the safeguards system very strict standards must be applied to the tolerable error range of C/S measures.

This can be illustrated by an example. In the intermediate storage of fuel elements to be reprocessed at a later stage, a diversion from the storage phase will be detected at the latest in measuring the material at the reprocessing plant. The effectiveness of the C/S measures during the storage period can thus at least be verified in retrospect. The longer the period to be bridged by C/S measures between two measurements in the material cycle, the higher are the requirements which must be made on the effectiveness of these C/S measures. If there is no longer any possibility of a final measurement then the C/S measures applied must provide the same reliability as a measuring process in order to be able to achieve the safeguards objective.

Only a relatively inadequate measurement of spent FE's is possible without chemical dissolution. If there is no reprocessing involving this measuring possibility then it could be argued that the whole FE repository should be more extensively and rigorously safeguarded. In addition to the problems already mentioned, others still have to be solved e.g. the tamperproofness of the individual components in the C/S system.

### 5.2.1 Application and Range of Effectiveness of Surveillance Measures (Inspector Presence and Optical Surveillance)

Optical monitoring is employed as a material flow indicator above and below ground: above ground at the hoisting facilities of the shafts in order to be able to detect the retransportation of FDP's via these facilities, and below ground in order to monitor the emplacement process and safeguard the tunnels against recovery of the material. For a number of years the IAEA has already been gathering experience in employing TV cameras for safeguards purposes. The problems arising here mainly concern the quality of the pictures and the reliability of the instruments. TV cameras have an advantage over film cameras due to their greater flexibility with respect to adapting to different conditions of application, in this case application as a low light-level or infrared camera and the possibility of being connected to other equipment such as the motion detector and also fading-in date and time. The problem of reliability is not so decisive for the final repository since a permanent inspector presence at the repository is required anyway. By means of automatic operational status monitoring it is possible to detect instrument defects within minutes or hours. These failures would have to be regarded as uncritical with respect to the safeguards objective due to the redundant safeguards design.

Due to the large number of optical safeguards instrumentations envisaged it seems meaningful to install a safeguards control room in the final repository from which the operational status of safeguards instruments can be permanently monitored and which also houses a central facility for storing and visually verifying the recorded frames. Due to the dimensions of the facility distances of several kilometers must be bridged between the monitoring instruments on site and the control room. Extensions and new developments are necessary to bridge these distances and to combine the individual instruments in one control room. The safeguards system envisaged for application in Candu reactors can be regarded as a comparable development, even if on a considerably smaller scale. This system is still currently at the development and trial stage and should be able to contribute valuable experience for designing camera safeguards in the final repository.

5.2.2 Application of Novel Safeguards Techniques

A number of possibilities for detecting diversion attempts can be conceived. In this context the application of microseismic instruments as sealing and containment surveillance devices for tunnels or fields already backfilled would have to be examined in detail. These instruments would have the task of indicating the application of mining equipment or drilling operations in tunnels and fields already backfilled. A further difficulty here is undoubtedly that tunnels are being backfilled and new tunnels simultaneously driven in relative proximity to each other so that considerable demands must be made on the spatial locating ability of the seismic instruments in order to be able to differentiate normal operational processes from potential diversion activities. It could possibly be of advantage here that emplacement is only envisaged in retreating working and thus the direction of a located source of vibration could be used as a differentiating feature for permissible and impermissible activities.

At any rate, the effectiveness of such detector messages would have to be investigated in detail since microseismic instruments have not yet been employed for safeguards purposes and thus no experience of any kind is available. Particular attention would have to be paid to the false alarm rates to be expected and the necessary subsequent operations, as well as possibilities of tampering and deception to conceal a diversion attempt. Since in conventional applications very much less importance generally has to be attached to these aspects considerable efforts will still have to be applied to determine these variables.

### 5.2.3 Application of Facility Safeguards

The possibility of permanent design reverification has already been envisaged as an additional measure for Safeguards Model 3. However, this measure has a similar effect to extensive facility safeguards and thus raises a large number of basic problems. The declared objective of the Federal Republic of Germany and the other EURATOM states has so far been to restrict IAEA safeguards to the material itself and to only grant the IAEA inspectors access to the predetermined strategic points. Conceding permanent design reverification represents a considerable deviation from this basic principle and should be examined in detail due to its possible trend-setting effect. In addition to the associated surrender of sovereign rights, this measure would also represent a considerable burden for the operator since the inspector would have to be accompanied by operating personnel during his inspections. It can admittedly be assumed that no commercial or industrial processes or equipment requiring protection are used in the final repository which would necessitate strict access controls, nevertheless restrictions on the inspector's freedom of movement with respect to time and place could be necessary to maintain an unimpeded operational sequence.

Extensive site surveillance could be considered in a similar or even more intensified manner as a further safeguard against the uncovering of an additional clandestine entrance. Extensive mining activities would undoubtedly be detected by monitoring a delimited area, e.g. by helicopter, for the purpose of visual site surveillance or aerial photographs. However, it must be considered whether the required losses of sovereignty are still acceptable.

As in all indirect safeguards, the essential aspect in this case is that the detection of an anomaly cannot be equated with a diversion. If these safeguards indicate an anomaly then this can only be used as a reason for closer examination. The contribution made by indirect safeguards within the framework of a safeguards concept terminates when in examining an indicated anomaly no satisfactory explanation can be found for it. At this point at the latest, safeguards must then be employed which make it possible to provide information about the presence of the material with quantifiable reliability.

## 5.3 Adaptation of the Reference Concept to Válid Safeguards Practice

With respect to the safeguards system the problematic aspects of the reference concept consist of the fact that

- the material must continue to be safeguarded even after emplacement and
- due to the inaccessibility of the material, the demands made in valid safeguards practice cannot be fulfilled with respect to verification possibilities.

Starting points for adapting the reference concept thus result by:

1. conditioning or storing the material in such a way that the criteria for terminating safeguards are fulfilled or
2. storing the material in such a way that it remains accessible for verification measures.

Conditioning the material in such a form that the criteria for termination could be regarded as fulfilled would require that the fuel be converted into a glass or ceramic product. This possibility has been considered in more detail by dissolving, diluting and compacting spent nuclear fuel. This was based on the conditioning of fuel in the form of PAMELA moulds. The essential data for this method of treatment resulted in approx. 465,000 PAMELA moulds per year of vitrified nuclear fuel at an annual throughput of approx. 700 tons. In order to emplace these moulds, approx. 6 - 8 shafts per geological repository would be required; a salt dome of the size of Gorleben would be able to accommodate a maximum of 425,000 moulds under the most favourable conditions /5-1/. This method can thus be ruled out as a realistic alternative.

In our opinion there is no possibility of unequivocally fulfilling termination criteria by the type of emplacement in the case of final disposal packages with undiluted nuclear material. Even in the case of borehole emplacement without lost shielding, envisaged as a back-up solution, recoverability of the material cannot be ruled out. All considerations of recoverability take the current state of mining engineering as a variable. Final release of the material from safeguards would require that the material should remain irrecoverable within the periods of time under consideration. Considering that even the inherent selfprotection of unshielded packages decreases with time and further progress in mining engineering must be presumed, the final classification of the material as irrecoverable will not be possible from the perspective of the safeguards authority, but this evaluation must rather be coupled to technological developments in mining engineering. This must be particularly considered in the light of high proliferation potential which the final repository represents for a state wishing to undertake a diversion.

I.e. in the case of undiluted conditioning of the final disposal products it cannot be expected that the material will finally be released from safeguards with respect to the two emplacement alternatives which can be taken into consideration (tunnel emplacement with lost shielding or borehole emplacement without lost shielding). The prerequisites for applying Article 35 VA are however fulfilled for both types of emplacement, namely that the recovery of nuclear material . . . is currently not possible nor desirable . . . In this case it is envisaged that the Agency and the Community should consult each other about the application of suitable safeguards. A statement on what the IAEA could regard as suitable safeguards is purely speculative at this point in time since there is no applicable experience. A process of intensive discussions with and between the safeguards authorities is necessary to elucidate this problem.

Emplacement in such a manner that the material remains accessible for verification would, apart from the technical feasibility, not fulfill the essential objectives of the final repository concept, namely isolating the material from the biosphere and possibilities of further human access. Accessible emplacement under ground would probably raise so many problems for reasons of heat dissipation and rock stability that this could no longer be regarded as a modification of the reference concept but would rather require a new concept to be compiled.

Under these assumptions the advantages of underground storage in comparison to storage above ground do not become immediately apparent. From the safeguards aspect storage above ground would undoubtedly be preferable since e.g. a diversion by simulated accidents blocking the entrance can be ruled out.

By way of summary it can be said that realistic possibilities of ensuring the safeguardability of the final repository according to current safeguards practice by modifying the reference concept cannot be envisaged at this time. Nevertheless, Art. 35 VA could represent a starting point for the discussion of a safeguards agreement deviating from current safeguards practice. Strictly speaking, the preceding considerations are only valid for the case of spent light-water reactor nuclear fuel. For fuels from special types of reactors, the criteria of Art. 11 of the VA could possibly make a termination of safeguards conceivable due to the different conditions in this case with respect to burn-up of the fuel, its dilution or the lack of an industrially applicable reprocessing procedure.

## 5.4 Possibilities of a Solution in the Institutional Sector

The starting point for institutional solutions is the fact that in order to implement a diversion, apart from the necessary technical measures, a considerable degree of organizational work must be undertaken. In the organizational sector additional barriers could be set up by multinational forms of cooperation which would impede the organizational implementation of a diversion and increase the risk of detection. A further aspect is possibly that the extension of international interconnections would increase vulnerability of the states to sanctions.

In the case of a final repository in an EURATOM member state, the logical consequence of the proprietary conditions is first of all considering the inclusion of EURATOM in the management and operation of the repository. The establishment of a direct final repository under the sole national control of a EURATOM state would presume that the Community had renounced its proprietary rights to the emplaced material. In view of the long-term proliferation aspects of the final repository, EURATOM's renunciation of proprietary rights and thus possible associated extended safeguards does not appear compatible with the objectives of the Community.

Pursuant to Art. 77 of the EURATOM Treaty, the Community undertakes to ensure that the nuclear materials are not employed for any purposes other than those envisaged. By final renunciation of its proprietary rights the Community would relinquish its otherwise derivable extended possibilities of codetermination and safeguards and would thus curtail its safeguards function. The final disposal of EURATOM material under the sole national control of a member state must therefore be classified as difficult to reconcile with the spirit of the EURATOM Treaty. It must also be examined whether it is desirable from a national point of view to operate a direct final repository under exclusive national control since a much greater obligation towards the international community can result from having to invalidate suspicious factors which could be interpreted as diversion attempts.

A conceivable alternative solution would be that a member state could implement final disposal on behalf of the Community, whereby Community conditions would have to be observed. This variant would correspond most closely to the interests of the Federal Republic of Germany. The Community's proprietary and safeguards reservations would thus be ensured and internationally verifiable. This model can also be evaluated as advantageous from the aspect of national acceptance.

The model with the highest institutional proliferation barrier would involve implementation of final disposal by the Community itself as a multinational undertaking where the member state would make available territory and infrastructure. Final disposal could thus ensue analogously to the deposition of nuclear material envisaged in Art. 80 of the EURATOM Treaty. However, from a national point of view this model raises significant acceptance problems since it implies the possibility of the final disposal of foreign material from EURATOM states. In view of the geographical and political situation of the Federal Republic of Germany it remains to be examined whether the extensive loss of sovereignty on the part of the host nation associated with this solution would be desirable.

The INFCE Conference provided essential impulses for considering institutional aspects and this is reflected in the IPS working group. It must, however, be remembered that institutional aspects are regarded by the IAEA as complementary, i.e. supplementary, measures and not as alternatives to stringent technical safeguards.

Due to the associated proliferation barrier, institutional models with multinational codetermination or cooperation undoubtedly represent an approach to the general NP problems of a final repository. However, they are not appropriate for solving the safeguards problem. In the first instance, institutionalization within the multinational EURATOM framework must be considered for a direct final repository in the EURATOM area as a consequence of the conditions of the EURATOM Treaty. From the point of view of the IAEA, this is hardly a drastic change in comparison to the current situation since the EURATOM area is already characterized by multinational safeguards. For the IAEA, institutional models would therefore have to go beyond the EURATOM framework and involve a form of international cooperation. Apart from the questions of the extent to which international cooperation can be implemented for a direct final repository and whether this is acceptable to the host country, the specific safeguards problem will not be solved by an international cooperation model either. Institutional models can thus be ruled out in the foreseeable future as an approach to solving the safeguards problems of a direct final repository.

# 6 CONCLUSIONS

The development of an internationally acceptable safeguards concept for the direct final repository raises a large number of problems which require intensive discussion with the safeguards authorities and which cannot be clarified a priori with the current state of the art.

| Final Disposal Phase | Safeguards Effectiveness Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| Phase 1: Transport above ground, leaving the conditioning facility - beginning shaft transport | acceptable | | |
| Phase 2: Transport below ground, beginning shaft transport - backfilling on site | acceptable since FDP's still accessible | | |
| Phase 3: Storage during the operational period, backfilling the FDP's - sealing the geological repository (backfilling the shafts) | unsolved problems | | |
| Phase 4: post-operational phase, after backfilling the shafts | unsolved problems | | |

**Table 6-1: Safeguards Effectiveness During the Various Operational Phases of the Final Repository**

As far as the effectiveness of safeguards possible at the present state of the art is concerned during the various operational phases of the final repository (Table 6-1), then the following can be ascertained: sufficient safeguards can be ensured both during the phase of transport above ground (Phase 1) as well as in the phase of underground transport of the final disposal packages until they are backfilled on site (Phase 2).

During the operational phase, the safeguards on the already emplaced final disposal packages (Phase 3) can consist of permanent design verification, although problems can be recognized in evaluating their effectiveness. The same is true of verifying the integrity of the shutdown repository in the post-operational phase (Phase 4).

An initial approach to solving the safeguards problem of a final repository (cf. Table 6-2) was envisaged in a modification of the existing IAEA safeguards philosophy. The IAEA would accordingly have to accept a safeguards model based essentially, or in the post-operational phase exclusively, on C/S measures. Since in this case the probability of detection, i.e. the essential parameter of IAEA safeguards, cannot be quantified at the present state of development, such an approach would be classified as unacceptable by the IAEA. If anomalies occur, e.g. in the case of a false alarm, the nuclear material cannot be verified.

Even a second approach envisaging the further technical development of safeguards elements cannot provide any basic solution to these inherent safeguards problems for the same reasons.

A third approach consists in modifying the reference concept, for example by dissolving and diluting the fuel, to ensure the safeguardability of the final repository according to current safeguards practice. No realistic possibilities are in sight in this case either, since this would cast doubt upon many of the desired characteristics of a direct final repository.

| Approach | Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| Alterations to the existing IAEA safeguards philosophy | IAEA would have to accept purely a C/S safeguards concept | | |
| | | | + intensive permanent facility safeguards |
| | ——— currently no solution ——— | | |
| Further and possibly redevelopment of safeguards elements | — no basic solution to the safeguards problem — | | |
| Adaptation of the reference concept to valid safeguards practice | —— no realistic possibility in sight —— | | |
| Institutional approaches | additional proliferation barrier but not a solution to the safeguards problems | | |

**Table 6-2: Assessment of the Solutional Approaches**

Institutional models with multinational codetermination or cooperation (fourth approach) undoubtedly represent a simplification of the NP problems in the final repository due to their associated proliferation barriers. Apart from the resulting questions of political acceptance they are not appropriate for solving the safeguards problem either. In this context, the establishment of a direct final repository must pay special attention to the role of EURATOM resulting from its proprietary and safeguards functions.

Before a final resolution, it is interesting to compare the essential NP aspects of direct final disposal with reprocessing. Table 6-3 shows this comparison with respect to differences in the fields of facility technology, safeguards technology and NP policy. This brief summary makes the advantages for a backend strategy with reprocessing quite clear.

On the basis of the facts and analyses compiled here the conclusion becomes obvious that a back-end strategy with direct final disposal is problematical from a safeguards aspect since doubt must be cast upon the technical realization of a safeguards concept.

For certain types of fuel element where reprocessing is not envisaged nor economical, Art. 35 of the VA can provide a possible solution. In the case of the limited emplacement of spent fuel elements, international safeguards could be negotiated pursuant to this Article.

| Reprocessing | Direct Final Disposal |
|---|---|
| **Technical Characteristics:** | ● Plutonium Determination |
| Pu determination after fuel dissolution, precision ± 1-2%; comparison with burn-up computations (destructive assay) | Pu determination planned by fuel element monitor, precision ≅ ± 5% (non-destructive assay) |
| | ● Whereabouts of the Plutonium |
| Pu separation by processing into MOX fuel elements | accumulation of Pu in underground final repository ("plutonium mine") |
| use of Pu in nuclear reactors | access to Pu increasingly easier due to decay of the fission products |
| | ● Technology |
| sensitive RP technology required, export control through international agreements | conventionally available mining technology |
| **Safeguards:** | ● Measures |
| Pu and U accountancy by analytical methods; complementary:<br>near real time accountancy, possibly containment/surveillance | item counting (operational phase)<br><br>containment/surveillance (after backfilling the tunnels) |
| | ● Evaluation |
| quantifiable IAEA guidelines with back-up measures | no back-up solution in the case of anomalies |
| **NP Policy:** | |
| Storage of excess separated Pu can be realized within a future IPS system | worldwide application of direct final disposal on the basis of long-term perspectives (social and political stability) undesirable |
| in the EURATOM area unrestricted utilization and consumption right | in the EURATOM area, politically undesirable consequences on the basis of proprietary rights to the nuclear material |

**Table 6-3: NP Aspects of Direct Final Disposal in Comparison to Reprocessing**

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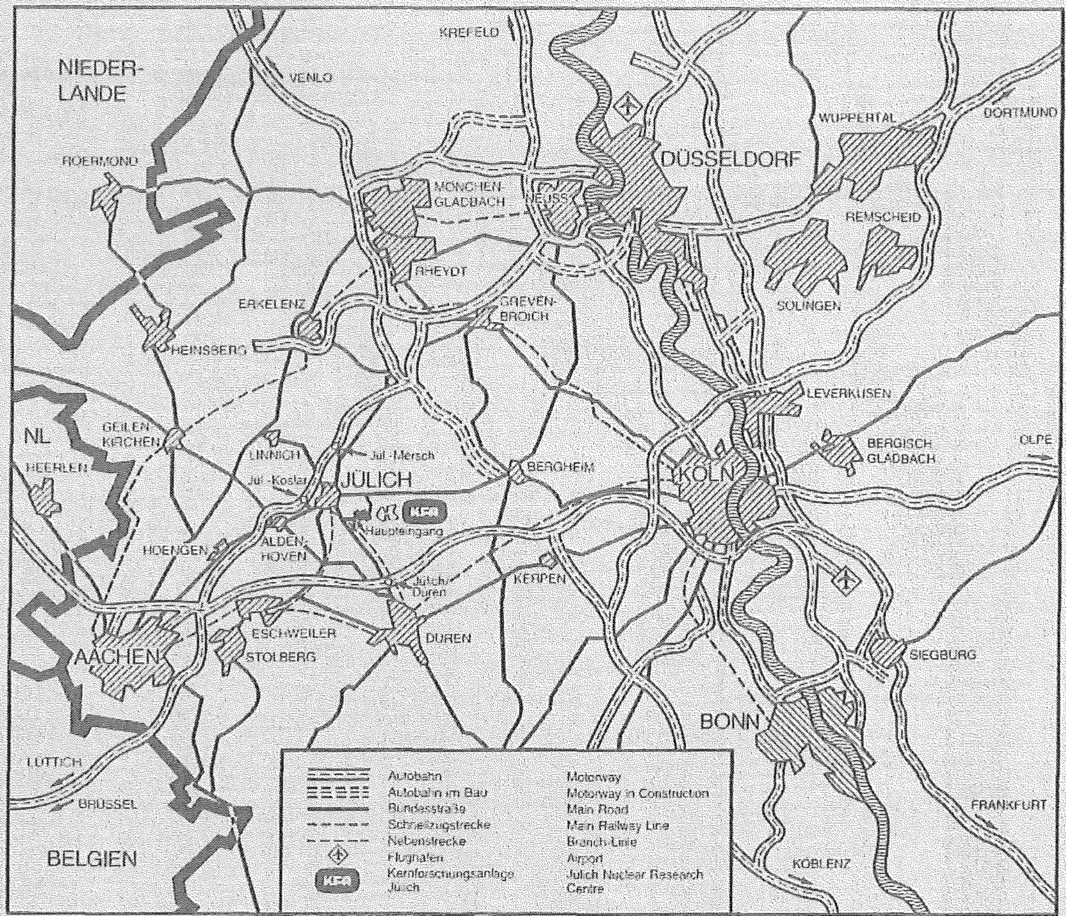
## 8 LIST OF ABBREVIATIONS

| | |
|---|---|
| AVR | Arbeitsgemeinschaft Versuchsreaktor GmbH |
| AWM | Alternative Waste Management |
| BHF | Bulk Handling Facility |
| C/S, CS | Containment/Surveillance |
| DBE | Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe (German Society for the Construction and Operation of Final Repositories for Waste Material) |
| DSB | Dry Storage Bin |
| DSP | Dry Storage Package |
| EURATOM | European Atomic Energy Community |
| FA | Facility Attachment |
| FDC | Final Disposal Canister |
| FDP | Final Disposal Package |
| FE | Fuel Element |
| HAW | Highly Active Waste |
| HC | Hot Cell |
| HM | Heavy Metal |
| IAEA | International Atomic Energy Agency |
| INFCE | International Nuclear Fuel Cycle Evaluation |
| IPS | International Plutonium Storage |
| ISFM | International Spent Fuel Management |
| KFA | Kernforschungsanlage Jülich GmbH (Jülich Nuclear Research Centre) |
| KfK | Kernforschungszentrum Karlsruhe (Karlsruhe Nuclear Research Centre) |
| KMP | Key Measurement Point |
| LS | Lost Shielding |
| LWR | Light Water Reactor |
| MBA | Material Balancing Area |
| MWd | Megawatt Day |

| | |
|---|---|
| NDA | Non-Destructive Assay |
| NMI | Nuclear Material Index |
| NP Treaty | Non-Proliferation Treaty |
| PAE | Projekt Andere Entsorgungstechniken (Alternative Waste Management Project) |
| PWR | Pressurized Water Reactor |
| RP | Reprocessing |
| SIR | Safeguards Implementation Report |
| SP | Strategic Point |
| SQ | Significant Quantity |
| THTR | Thorium High-Temperature Reactor |
| TUG | Programmgruppe Technik und Gesellschaft (Programme Group Technology and Society) |
| VA | Verification Agreement |
| VACOSS | Variable Coding Seal System |
| WSQ | Weighted Significant Quantity |

# 9 LIST OF TABLES

## 10 LIST OF FIGURES

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# INTERNATIONAL SAFEGUARDS FOR A GEOLOGICAL REPOSITORY FOR THE FINAL DISPOSAL OF SPENT LIGHT-WATER POWER REACTOR FUEL

by

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Contribution to the R+D Programme
Alternative Waste Management Techniques
of the Federal Ministry
for Research and Technology

## SUMMARY

On the basis of the reference concept evolved within the framework of the research and development programme "Alternative Waste Management Techniques", safeguards concepts for a direct final repository are being compiled and evaluated. The safeguards under discussion begin with the arrival of the products for final disposal at the reception area of the geological repository and terminate with the measures envisaged for the post-operational phase of the repository. Safeguards for the conditioning facility or the transport of final disposal packages are not included in this study.

First of all in Chapter 2, important aspects of the reference concept have been selected and compiled for safeguards applications. The considerations are based on a standard PWR fuel element of the Biblis B type with a burn-up of 40,000 MWd/t HM at an initial enrichment of 3.6 %. After a cooling-down period of at least 10 years, the spent fuel elements are transferred in flasks of 12 fuel elements each to a conditioning facility which need not necessarily be at the site of the final repository. Conditioning is implemented in two sub-steps, preliminary conditioning and final conditioning. During preliminary conditioning three intact fuel elements are enclosed gas-tight in a so-called dry storage bin. The resulting intermediate storage package is brought into the final conditioning sector in a final disposal canister. A facility capacity of 700 t of heavy metal per year requires that 6 - 9 fuel elements be conditioned per day. 2 - 3 final disposal packages per day thus result in the final conditioning sector.

The geological repository is constructed in a virgin salt dome, the reference concept envisaging emplacement in tunnels with lost shielding. Access to the repository is obtained via two shafts. The first shaft serves to transport the salt, material and personnel. The second shaft is envisaged for

emplacement and special transports. Air inflow is effected via Shaft 1; exhaust air flows out through Shaft 2. Exploration of the envisaged emplacement area is implemented by exploratory drillings and tunnels. The exploratory tunnels roughly demarcate the emplacement area and are later to be used as ventilation galleries for exhaust air from the emplacement fields. After completing underground exploration, the position and size of the emplacement fields is determined. The emplacement floor will probably be 30 m below the exploratory floor at a depth of between 700 m and 900 m. Access to the emplacement area is obtained by driving two parallel access galleries joined by connection drifts at intervals of 200 m. Starting from the connection drifts, the emplacement galleries are driven parallel to the access galleries. Before beginning emplacement, emplacement galleries will only be driven starting from the emplacement connection drift furthest from the shaft. Emplacement galleries are driven from the next connection drift at the same time as emplacement is implemented in the first sector of the emplacement field.

The final disposal package is transported under ground on a rail-bound plateau transporter via Shaft 2. Underground transport to the emplacement connection drift is rail-bound; whereas transport through the emplacement connection drift to the emplacement gallery is railless. This is effected by an emplacement vehicle. After emplacing the package, the gallery section with the package is backfilled (mechanical or pneumatic stowing). When all the galleries of an emplacement sector are occupied by packages and filled-in the emplacement connection drift and ventilation galleries are also backfilled. After terminating emplacement operation - 40 weeks' operation per year, 11 FDP's per week - all the galleries and cavities are backfilled, in the same way as the shafts. It is intended to operate the mine for 50 years at an emplacement rate of 437 FDP's per year.

The NP aspects of a direct final repository are dealt with in Chapter 3. The accumulation of plutonium in a direct final repository is regarded as especially dubious with respect to non-proliferation ("plutonium mine"), since in principle later access by a nation to the very large quantities of plutonium can never be ruled out. Due to the large quantities of stored plutonium and the long operational period of such a repository, it must finally also be remembered that notice to or termination of the Non-Proliferation Treaty cannot be ruled out in various countries.

In this connection, the results and considerations of the INFCE Conference are of special importance. INFCE Group 7 WASTE MANAGEMENT AND DISPOSAL concerned themselves with the problems of safeguards in final repositories for spent fuel elements. INFCE considered it possible in principle to safeguard such a repository during the operational phase with safeguards techniques currently available. However, in the long term INFCE doubts the effectiveness of safeguards since the post-operational phase lasting for centuries will be determined by numerous unforeseeable technical, political and social factors.

In addition to the political and technical boundary conditions, three safeguards models are presented in Chapter 4 intended to ensure the safeguarding of a final repository. The models are differentiated by the degree of authorized access for IAEA inspectors. Thus in Model 1 access is restricted to aboveground facilities, Model 2 envisages limited access to the underground facilities and Model 3 unrestricted access to all underground facilities.

In Model 1 the inspector's access is limited to strategic points above ground. These strategic points are the key measurement points, the reloading facility above ground as well as the bank eyes of the mine shafts. The essential element of this model is that, after the material has been taken under ground, recovery or an internal diversion within the mine is ruled out. By transferring the material under ground, it is thus released from safeguards monitoring and written off. Since according to its definition there is no longer any material subject to safeguards present in this model after emplacement activities have been completed, neither is there any need for safeguards during the post-operational phase.

Before the material can be released from safeguards, proof of non-recoverability must be presented. If this cannot be presumed then routine inspections of the site will be required during the post-operational phase in order to monitor activities which could indicate a reopening of the mine or other measures for recovering the material.

The basic prerequisite for Model 1 is that the final repository itself can be regarded as a sufficient barrier so that measures can be dispensed with for ensuring that there is no undeclared containment opening through which the material could be recovered and that a diversion of material within a containment (reprocessing under ground) can be ruled out.

Model 2 comprises Model 1 and the following additional underground strategic points: pit bottom of both shafts, intersections of the access galleries with the emplacement connection drifts and the junctions of the emplacement galleries with the respective connection drift. These underground strategic points enable the inspector to safeguard the underground nuclear material flow at various stages of intensity. Largely the same restrictions as for Model 1 apply to this model. A termination of safeguards with backfilling of the gallery would have to be possible, or the geological repository itself would have to be regarded as a sufficiently safe barrier. The access of inspectors to strategic underground points would indeed present a serious obstruction to a diversion in the geological repository, but it cannot be ruled out with sufficient certainty.

Model 3 comprises Model 2 and moreover as an additionl measure the access of inspectors to all underground facilities and installations. Measures for containment and/or surveillance are thus suggested in all the aboveground and underground facilities and installations of the final repository, including the waste storage area.

Based upon these three safeguards models, a diversion and abuse analysis has been compiled as well as an evaluation of effectiveness leading to the following results: sufficient safeguards can be ensured both in the phase of aboveground transport (Phase 1) as well as in the phase of transporting the final disposal package under ground until it is filled-in on site (Phase 2). During the operational phase safeguards on final disposal packages already backfilled (Phase 3) can consist of permanent design reverification (Safeguards Model 3); however, unsolved problems can be seen in evaluating their effectiveness. The same is true of verifying the integrity of the shut-down geological repository in the post-operational phase (Phase 4).

In Chapter 5 approaches are suggested and discussed for solving the safeguards problem. An initial approach is perceived in altering the existing IAEA safeguards philosophy. The IAEA considers it necessary to quantify objective variables by compiling numerical detection objectives (significant quantity, detection time, probability of detection, probability of false alarms). The probability of detection is the essential variable in the IAEA safeguards towards which the planning of safeguards, employment of resources and evaluation of effectiveness are oriented. Since there is currently no procedure for quantifying the probability of detection in applying containment and surveillance measures, safeguards models which are largely or, as required in the case of the final repository, almost exclusively based on C/S measures, cannot be objectively planned in this model nor is their effectiveness computable. This leads to them being classified as unacceptable by the IAEA.

A second approach is seen in the further development, and possibly redevelopment, of safeguards elements. In the operational phase of the final repository the problem consists in communicating a quantifiable certainty to the safeguards authority by suitable measures that the emplaced material is still present. Strictly speaking this quantification is only possible for accountancy measures. No methodology has yet been developed for numerically determining the information content of C/S measures; the error associated with C/S verification cannot be precisely specified. This problem can generally be mitigated in other facilities by implementing material verification in principle by accountancy measures and by only employing C/S measures for subsidiary quantities of material and for limited periods as a supportive measure. These restrictions (limitation to subsidiary quantities and defined periods) must be dispensed with in the case of the final repository. Safeguards would thus only be possible with purely a C/S concept and there is no contractual nor methodological basis for this. I.e., even presuming that safeguards elements were to be redeveloped or further developed, thus enabling C/S-supported monitoring of the emplaced material, its inclusion in the safeguards system would only be possible as a supplementary measure. On their own they do not represent a basic solution to the problem under consideration.

Adaptation of the reference concept to the currently valid safeguards practice is discussed as the third approach. The starting points for this discussion are conditioning the material in such a way (dissolution and dilution) that the termination criteria for safeguards monitoring are fulfilled, or emplacing the material in such a way (recoverable) that it remains accessible for verification measures. Both methods of treatment are unacceptable as realistic alternatives. By dissolving the fuel and conditioning in the form of PAMELA ingots the capacity e.g. of the Gorleben salt dome would not even be sufficient for a single annual throughput of 700 t of nuclear fuel. By emplacement in such a way that the material would remain accessible for further verification, apart from the technical feasibility, the essential objectives of the final repository concept would not be fulfilled, namely isolating the material from the biosphere and from possible further human access. Accessible underground emplacement would probably raise so many problems for reasons of heat removal and rock stability that this could no longer be regarded as a modification to the reference concept but would rather require compiling a new concept.

As a fourth approach, possibilities for solutions in the institutional sector are discussed. The starting point for institutional approaches is the fact that in order to implement a diversion a considerable amount of organizational work must also be undertaken in addition to the necessary technical measures. By forms of multinational cooperation, additional barriers could be erected in the organizational sector which would make a diversion more difficult and would increase the risk of detection. A further aspect is that by extending international involvements, the states would probably be more vulnerable to sanctions.

Consideration of institutional aspects received essential impulses through the INFCE Conference and is reflected in the IPS Working Group. It must, however, be remembered that institutional aspects are regarded by the IAEA as supplementary measures and not as an alternative to stringent technical monitoring. Institutional models with multinational codetermination or cooperation undoubtedly represent an approach to general NP problems of a final repository due to the associated proliferation barrier. However, they are not appropriate for solving the safeguards problem. In this connection the special role of EURATOM will be discussed, which has proprietary rights to nuclear material and special rights in the storage of nuclear material on the basis of contractual boundary conditions.

An evaluation of the approaches mentioned above is undertaken in Chapter 6. The first approach to the safeguards problems of a final repository was seen in modifying the existing IAEA safeguards philosophy. According to this the IAEA would have to accept a safeguards model based largely - or in the post-operational phase exclusively - on C/S measures. Since in this case the probability of detection, i.e. the essential objective of IAEA safeguards, cannot be quantified at the present state of the art, such an approach would be regarded as unacceptable by the IAEA. It is not possible to verify the nuclear material in the case of anomalies, e.g. false alarms.

For the same reasons the second approach, envisaging the further technical development of safeguards elements, cannot be presented as a basic solution to these inherent safeguards problems either.

The third approach consists in ensuring the safeguardability of the final repository according to current safeguards practice by altering the reference concept (e.g. by dissolving and diluting the nuclear fuel). No realistic possibilities are in sight in this case either, since doubt is thus cast on many of the desired characteristics of a direct final repository.

Institutional models with multinational participation and co-operation (fourth approach) undoubtedly represent a simplification of the NP problems of the final repository due to the associated proliferation barriers. But in addition to the resulting problems of political acceptance they are not suitable for solving the safeguards problem either. In this context the role of EURATOM, resulting from its safeguards functions and its proprietary rights to all special fissionable materials, must be taken into particular consideration in establishing a direct final repository.

Before a concluding resolution, it will be of interest to compare the essential NP aspects of direct final emplacement with reprocessing. This comparison clearly reveals the advantages of a waste disposal strategy with reprocessing.

On the basis of the facts and analyses compiled, the conclusion becomes apparent that the waste management strategy with a direct final repository is problematic from safeguards aspects since doubt is cast on the technical realization of a safeguards concept.

For certain types of fuel element where reprocessing is not envisaged and not worthwhile, Art. 35 VA can offer a possibility of a solution. In this case of the limited emplacement of spent fuel elements it could be possible to negotiate international safeguards according to this Article.

CONTENTS

Page

# 1 INTRODUCTION

The possibility of the direct final disposal of spent fuel elements is considered as an alternative to the commercial reprocessing of fuel elements. Final disposal aims at isolating radioactive material from the biosphere and from possibilities of accidental human access without any time limit. The safety concept is designed to ensure the integrity of the repository without requiring human maintenance or monitoring after the final closure of the repository. Final disposal is conceived of as irreversible disposal.

Within the framework of the research and development programme "Alternative Waste Management Techniques" the emplacement of spent fuel elements in a salt dome is being studied. Several concepts have been compiled for conditioning, for the final disposal canister and emplacement techniques for this direct final disposal of spent fuel elements. One concept which best fulfills the criteria of safety engineering, technical feasibility, availability of raw materials, and also approaches to economic efficiency and nuclear materials safeguards, was selected as a reference in each case. Back-up solutions for each component were also determined over and above establishing the reference concepts.

A nuclear materials safeguards concept is to be developed by the KFA-TUG on the basis of the reference concept. This safeguards concept for Alternative Waste Management comprises safeguarding the products for final disposal from their arrival at the geological repository. Individual aspects important for applying international safeguards measures have been selected and compiled in Chap. 2 from the large volume of information required for this concept and from detailed technical problems already known.

The reference concept is based on a pressurized water reactor standard fuel element of the Biblis B type with a burn-up of 40,000 MWd/tHM at an initial enrichment of 3.6 %.

After a cooling-down period of at least 10 years the spent fuel elements are transported in flasks of 12 fuel elements each to a conditioning facility. Conditioning is effected in two steps, preliminary conditioning and final conditioning. In order to ensure that its capacity is continuously exploited the facility has a reception store for approx. 20 flasks.

The spent fuel elements are enclosed in a final disposal package (FDP) in the conditioning plant. An FDP consists of three containers: the dry storage bin (DSB) as a gas-tight barrier, the final disposal canister (FDC) primarily designed according to the criteria of corrosion protection and stability, and the lost shielding (LS) which serves as a protection against neutron and gamma radiation during handling and transport.

The finished FDP's are transported from the conditioning facility to the geological repository in special flasks on special freight cars owned by the Deutsche Bundesbahn (Federal German Railways). The FDP's are taken out of flasks and individually loaded onto plateau transporters at the reloading plant of the geological repository for transport under ground. A reception buffer store serves to accommodate FDP's in the case of disturbances in emplacement operation. During normal operation the FDP's delivered are taken directly under ground and there emplaced according to regulations.

With respect to nuclear materials safeguards, no experience is yet available for direct final disposal. From the point of view of proliferation, a final repository for spent fuel elements containing strategic material represents an increasingly attractive object for a potential diverter and thus requires effective safeguards for which new techniques and concepts must be developed due to the special problems involved.

Safeguards instrumentation currently available is based on material accountancy and independent material verification which in the case of a final repository with the purpose of isolating material from the biosphere and preventing further possibilities of access can no longer be directly applied.

In the following the direct final emplacement of spent fuel elements, an interesting possibility also for other states, is therefore investigated from safeguards aspects with respect to the Féderal Republic of Germany which, in contrast to other signatory states of the NP Treaty, does not have a national safeguards system. Whether and to what extent available safe-guards elements can be combined into an effective safeguards concept is analyzed under the boundary conditions given for the final repository, or which modifications may possibly be necessary.

# 2 TECHNICAL REFERENCE CONCEPT WITH SPECIAL REGARD TO SAFEGUARDS

## 2.1 Conditioning the Products for Final Disposal

### 2.1.1 Preliminary Conditioning

In the preliminary conditioning functional area 3 intact fuel elements are each enclosed gas-tight in a so-called dry storage bin (DSB). The individual process steps are distributed between 3 separate cells connected to each other by a DSB transport vehicle coupled to the cell openings in a ventilatively tight manner. The preconditioning sequence proceeds as follows:

The flasks taken from the reception buffer store are docked onto the opening in the floor of the fuel element unloading cell. After removing the fuel elements (FE), they are examined and deposited in the FE buffer store.

After docking the DSB onto the opening in the floor of the fuel element buffer cell, the lid of the opening is opened and the fuel elements placed in the DSB. The fuel elements are transported suspended on a cell crane when removing them from the fuel element buffer store. The trap door in the bin-loading cell is then closed again and the loaded DSB proceeds to the next cell, the welding cell.

In the welding cell the screw cap is inserted in the DSB and welded on. Helium is then fed in for the subsequent leak test and the filling hole is closed by welding.

The transport vehicle then proceeds to the opening in the floor of the testing cell and is coupled to the cell opening. In the testing cell the dry storage bin is taken over by the cell crane. The DSB transport vehicle is uncoupled and proceeds to the material transfer room where it is loaded with an empty dry storage bin. The welded DSB is taken to the decontamination device in the testing cell and after a wipe test is decontaminated if necessary. The DSB is subsequently subjected to an integral helium leak test in a pressure container and then after passing the test is transferred out of the cell and placed in a buffer store.

The dry storage bin used during preliminary conditioning can accommodate three intact fuel elements. It consists of a tube, bottom, cap and internals. On the lid there is a device for suspending it from a crane. The tube length of the DSB is 5.14 m, the tube diameter is 66.5 cm and the walls are 8 mm thick.

As a parallel approach to the preliminary conditioning described above, the method of "Fuel Elements Separated Into Fuel Rods" is currently being investigated. This will not be discussed in detail here since those components of the final disposal package relevant to safeguards in the final repository are practically unaltered by this alternative method of treatment.

### 2.1.2 Final Conditioning

The process steps in final conditioning begin by taking over the dry storage package (DSP), that is to say the loaded DSB, from the buffer store in preliminary conditioning and are terminated by passing on the final disposal package. In order to take over the DSB, an empty FDC is driven on a railway truck under the outward transfer room of the preliminary conditioning. The dry storage package coming from the buffer store is placed in the final disposal canister by the crane. The railway truck then transports the loaded FDC under the inward transfer room of final conditioning.

The final disposal canister is first raised here by means of lifting tackle on the railway truck and the lid is placed in position by the cell crane and then screwed on. The crane then picks up the FDC and deposits it at the welding facility. Automatic welding equipment applies the seal weld of the second lid at several positions. The weld seam is then visually inspected and a helium leak test then follows for liquid-tightness.

The tested final disposal canister is then inserted in the lost shielding by the cell crane located in the output transfer room. The lost shielding is closed by means of a screw cap. The final disposal package in a Type B flask then proceeds to the geological repository on a special Federal Railways truck.

The final disposal canister is intended to ensure the safe containment of the radioactive material for a period of about 500 years. Due to the geometry of the intact fuel elements, a maximum length for the final disposal package of 6.2 m would seem to be appropriate. This weighs approx. 50 t, it is designed for a heat output of 2.4 kW.

Nine fuel elements must be conditioned per day in order to achieve an annual capacity of 700 t heavy metal; the preliminary conditioning functional area is therefore designed in two legs. 2 - 3 final disposal packages therefore reach the final conditioning functional area per day.

## 2.2 The Geological Repository

### 2.2.1 Specifications

The geological repository will be constructed in a virgin salt dome. The reference concept envisages emplacing FDP's with lost shielding in tunnels. The emplacement level is to be at a depth of approx. 730 m. The repository is to be operated for 50 years at an emplacement rate of 437 final disposal packages per year. With 40 operating weeks per year two final disposal packages must be emplaced on four days of the week and three final disposal packages on one day, i.e. 11 final disposal packages per week. Only one emplacement level is envisaged. A maximum temperature of 200°C is presumed for the salt in the emplacement area, as in the HAW concept. It is hoped to achieve a temperature of 150°C at the salt-canister interface. Before beginning emplacement the rock temperature at a depth of 730 m is approx. 37°C.

| | |
|---|---|
| Number of Shafts | 2 |
| Internal Diameter of the Shafts | 7.50 m |
| Shaft Intervals | approx. 400 m |
| Working Load Shaft I | 25 t |
| Working Load Shaft II | approx. 60 t |

**Table 2-1: Shaft Data**

The shaft transport equipment for emplacement operation is to be designed for a working load of approx. 60 t. At the same time as emplacing fuel element packages from fuel conditioning, secondary waste is emplaced via the same shaft but in a separate emplacement field.

| | |
|---|---|
| Operational Life . . . . . . . . . . . . . . . . . . . . . . . . . . . | 50 a |
| Depth of the Emplacement Level . . . . . . . . . . . . . . . . . | approx. 730 m |
| Emplacement Rate for FE Packages . . . . . . . . . . . . . . | 2 or 3 per day |
| Admissible Temperature of the Salt in the Emplacement Area . . . . . . . . . . . . . . . . . . . . . . . . | max. 200°C |
| Temperature at the Salt-Canister Interface . . . . . . . . . . | approx. 150°C |
| Rock Temperature Before Beginning Emplacement . . . . . | 37°C |
| Working Load of the Shaft Transport Equipment for Emplacement Operation . . . . . . . . . . . . . . . . . . . . . | approx. 60 t |
| Products for Final Disposal . . . . . . . . . . . . . . . . . . . | Spent LWR-FE's, waste from the conditioning facility, nuclear power stations, regional collecting depots, research establishments etc. |
| Cross Section of the Tunnels in the Emplacement Floor . . . | approx. 22 $m^2$ |

**Table 2-2: Specifications for the Geological Repository**

| | |
|---|---|
| Cross Section of the Exploratory Tunnels . . . . . . . . . | approx. 15 $m^2$ (without vaulting) |
| Connection Drift Intervals . . . . . . . . . . . . . . . . . . . | 200 m |
| Distance of the Emplacement Floor from the Exploratory Floor . . . . . . . . . . . . . . | 30 m |
| Access Gallery Intervals . . . . . . . . . . . . . . . . . . . . | 500 m - 1800 m |
| Dimensions of the Emplacement Fields . . . . . . . . . . . | 500 x 200 $m^2$ to 1800 x 200 $m^2$ |
| Cross Section of the Access Galleries and Connection Drifts . . . . . . . . . . . . . . . . . . . . | 7 x 4 $m^2$ |
| Cross Section of the Emplacement Tunnels . . . . . . . | 5 x 4 $m^2$ |
| Thickness of the Pillars from the End of the Emplacement Gallery to the Next Connection Drift . . . . | 7 m |
| Ascending Gradient of the Connection Galleries . . . . . | 10 - 12 % |

**Table 2-3: Data on the Position and Dimensions of Tunnels and Fields**

### 2.2.2 Developing the Geological Repository

A final evaluation on the suitability of the salt dome requires underground exploration by mining development. This mining development will not be conventional, i.e. largely without blasting. Access to the repository will be obtained via two shafts each 7.5 m in diameter at a distance of approx.

400 m. The first shaft serves for removing salt, transporting the material, man-riding and the incoming air. The working load of the transport facility is approx. 25 t. The second shaft, where the transport facility has a working load of approx. 60 t, serves for emplacement transport and the exhaust air.

Exploration in the envisaged emplacement area is undertaken by exploratory drillings and tunnels. The exploratory tunnels will have a cross section of 5 x 3 $m^2$ without vaulting. They roughly delineate (deviation of up to 25 m) the emplacement field and will later be used as ventilation galleries for the exhaust air from the emplacement fields.

The underground infrastructure area will be constructed between the two shafts. This includes the pit bottom, hopper, crushing and dust-removing facilities, as well as workshops for the assembly and maintenance of the machines, facilities and motor vehicles used under ground. The planned dimensions of the mechanical workshop are given in Table 2-4. The workshop is equipped with lifting platforms. A travelling crane with a load of 25 t is envisaged.

| Dimensions of the Workshop | |
|---|---|
| Length | 85 m |
| Width | 15 m |
| Height | 6 - 8 m |
| Load of the Travelling Crane in the Workshop | max. 25 t |

**Table 2-4: Data on the Workshop**

The position of the emplacement fields will be determined after completing underground exploration. The emplacement floor will be 30 m below the exploratory floor.

Access to the emplacement area will be obtained by driving two parallel access galleries up to the boundaries of the field. The access galleries are joined by connection drifts at intervals of 200 m. The emplacement galleries are driven parallel to the access galleries starting from the connection drifts. The emplacement tunnels are not driven right through so that a pillar of 7 m remains between the end of the tunnel and the next connection drift. The access galleries and connection drifts have a cross section of 25 $m^2$, the emplacement tunnels 18 $m^2$. The distance between the two access galleries depends on geological conditions in the salt dome and may be between 500 m and 1800 m. The individual emplacement fields correspondingly have dimensions of 500 m x 200 m to 1800 m x 200 m. In the final disposal package emplacement field, 18 connection drifts with 50 emplacement tunnels each and 1 connection drift with 40 emplacement tunnels are planned. Only the emplacement tunnels of the connection drift furthest from the shaft will be driven before beginning emplacement. The emplacement tunnels in the next emplacement connection drift are driven at the same time as emplacement is effected in the adjacent emplacement connection drift.

The emplacement floor is connected to the infrastructure area on the exploratory floor in the form of sloping tunnels as belt and chute raises with an ascending gradient of 10 - 12 %.

### 2.2.3 Emplacement Operation

Emplacement is effected by retreating working, i.e. from the most remote boundaries of the underground excavations towards the shafts. Before beginning emplacement, all emplacement tunnels are first driven in the field furthest from the shaft. A pillar of 15 m remains between the first emplacement tunnel and the access gallery. The width of the pillars between the emplacement tunnels is 10 m. After the first emplacement connection drift has been completely driven, emplacement operation will begin in it. Tunnelling the second connection drift proceeds parallel to emplacement.

The final disposal package is transported below ground on a rail-bound plateau transporter via the shaft envisaged for emplacement operation (cf. the sequence diagram in Fig. 2-1). The plateau transporter does not have any driving mechanism of its own and no brakes, and has to be propelled by a locomotive. The technical specifications are given in Table 2-5.

| Plateau Transporter | |
|---|---|
| Length . . . . . . . . . . . . . . . . . . . . . . . | approx. 6.0 m |
| Width . . . . . . . . . . . . . . . . . . . . . . . | approx. 2.5 m |
| Weight . . . . . . . . . . . . . . . . . . . . . . . | approx. 8 t |
| Axle Load . . . . . . . . . . . . . . . . . . . . . | approx. 35 t |
| Track Gauge . . . . . . . . . . . . . . . . . . . | 1.435 m (Federal Railway gauge) |

**Table 2-5: Plateau Transporter Data**

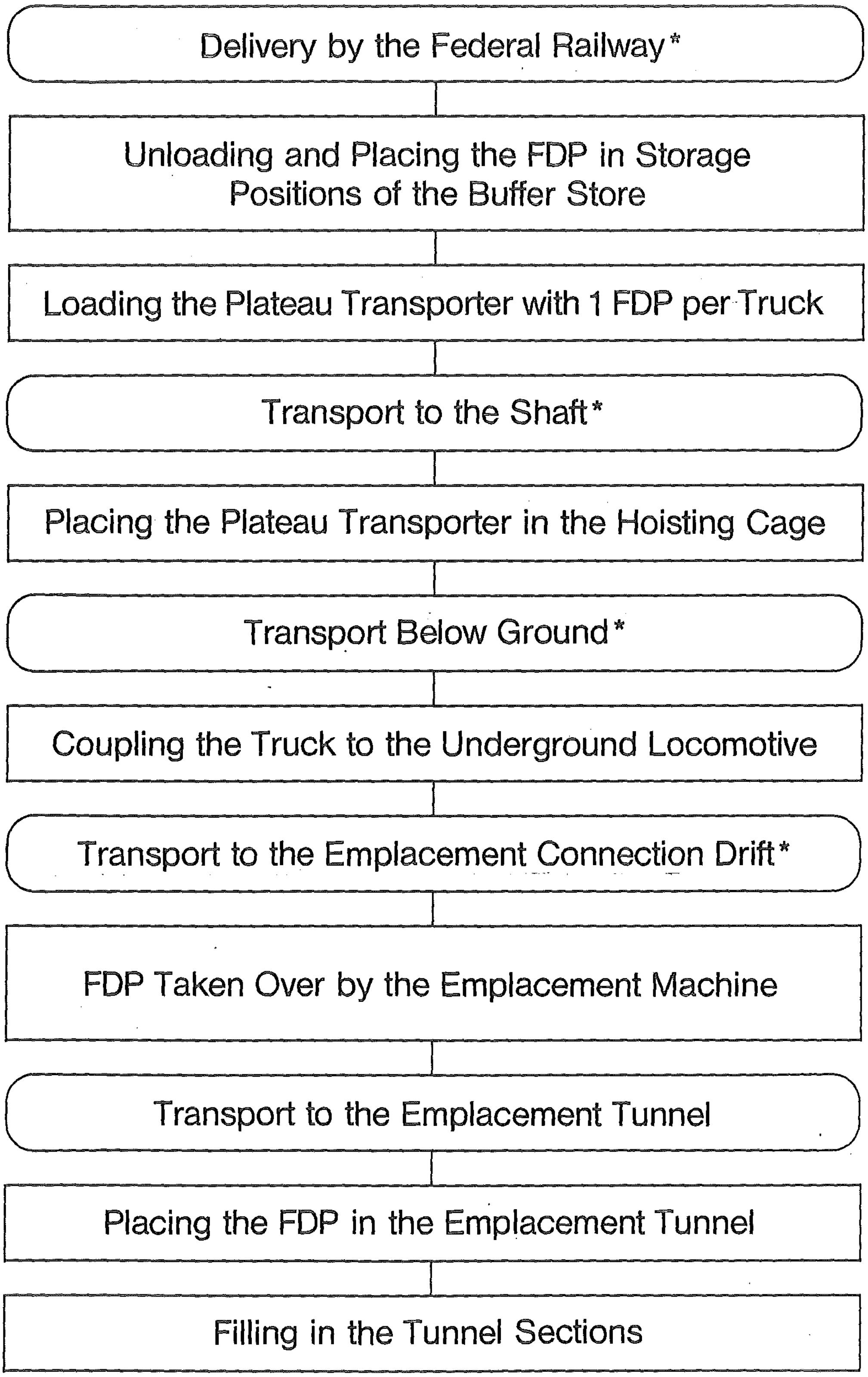
The plateau transporter with the final disposal package is driven into the hoisting cage of the shaft winding equipment, is secured and transported through the shaft to the emplacement floor. A locomotive then takes over the transportation and drives the plateau transporter on rails along the access gallery solely designed for package transport to the emplacement connection drift. The gauge also corresponds to Federal Railway standards. Still on the access gallery, the emplacement machine takes over the package from the plateau transporter at the intersection of the connection drift and tunnel, and transports it without rails through the emplacement connection drift to the emplacement tunnel. After placing the package at the location of emplacement, the emplacement machine returns to the access gallery where the plateau transporter has in the meantime been driven back to the shaft and then taken to the surface. The section of the tunnel with the FDP is then filled in with crushed salt for a distance of 7.5 m. Mechanical or pneumatic stowing is used as the filling process. The filling vehicle is a railless vehicle with sliding sides on which a mechanical stowing machine is mounted. The emplacement sequence is shown in Fig. 2-1.

The stowing material is fed to the stowing machine via a conveyor system from the advanced working or a hopper. Aggregates in the form of MgO concrete can be added. The stowing machine drives to the emplacement location and mechanically fills the section of the tunnel to be closed. This method achieves a 98 % degree tunnel filling.

The distance between adjacent emplacement connection drifts is 200 m. Since 7 m remains as the end pillar and 13 m is required for barricading the filled-in section, 180 m can be used for emplacing the packages. With a package length of 6.2 m and a distance between the packages of approx. 1 m, a tunnel can accommodate 24 packages.

If all the tunnels of an emplacement connection drift are occupied by packages and filled in, then the emplacement connection drift, the parallel and flanking galleries, as well as the ventilation galleries (if they are no longer required) are filled in and closed by dams. Table 2-6 shows the most important data of an emplacement field.

At the same time as emplacement is being effected, the next sector of the emplacement field relative to the shaft area is opened up. The galleries are driven by a cutting tunnelling machine. The debris is either removed by direct belt feed and transportation via the conveyor system as stowing material to the emplacement location, a hopper area or the pit bottom at Shaft I. Or alternatively




* Rail-Bound Transport

Figure 2-1 : Diagram of the Emplacement Sequence a shovel loader takes over the debris from the tunnelling machine and transports it to the belt feed. All transportation of debris in the emplacement sector is railless and is effected without exception through the connection drifts to the access gallery not used for emplacement transport. The maximum distance covered by the shovel loader to the belt feed is approx. 300 m. The hopper area is a maximum of 2 km from the emplacement location on the access gallery.

| | |
|---|---|
| Width of the Pillar Between the Access Gallery and the First Emplacement Tunnel . . . . . . . . . . . . . . . . . . . . . . . | 15 m |
| Width of Pillars Between the Emplacement Tunnels . . . . . . . | 10 m |
| End Pillar Between the Emplacement Tunnel and Next Connection Drift . . . . . . . . . . . . . . . . . . . . . . . | 7 m |
| Length of the Closure Plug of an Emplacement Tunnel . . . . . | 13 m |
| Effective Length of the Emplacement Tunnel . . . . . . . . . . . | 180 m |
| Package Length . . . . . . . . . . . . . . . . . . . . . . . . . . . . | 6.2 m |
| Distance Between Two Packages . . . . . . . . . . . . . . . . . . | approx. 1 m |
| Number of Packages Per Tunnel . . . . . . . . . . . . . . . . . . | 24 |

**Table 2-6: Dimensions in the Emplacement Field**

After terminating emplacement operation, all the tunnels and cavities are filled in and closed by plugs and dams. The shafts are also filled, whereby the natural geological structures are largely taken into consideration. Barriers of concrete and asphalt are also incorporated. Although the walls of the shaft are not removed, it will be impossible to use the shafts again.

### 2.2.4 Machines and Vehicles

The following machines and vehicles are available in the geological repository for developing the mine and filling in the tunnels after emplacement:

- cutting tunnelling machine
- shovel loader
- mechanical stowing machine.

These machines and vehicles are partly diesel-driven or they have electric engines and are railless. As self-propelled vehicles they can be equipped with a tachograph to record the distance covered, driving time and speed. The cutting tunnelling machine weighs approx. 80 t and can be equipped with an air-conditioned cab. However, this is not envisaged at the prevailing work temperature of 37°C. The shovel loader weighs approx. 25 - 30 t and is not suitable for transporting final disposal packages. The machines and vehicles described here can be used both in the FDP store as well as in the waste store. In addition to the vehicles mentioned, vehicles for inspection, transporting crews and material, clearing, loading and special purposes are used both in the mining and emplacement sector. The following are envisaged for emplacement operation:

- plateau transporter
- locomotive
- emplacement machines.

The plateau transporter is rail-bound and is not self-propelled. It weighs 8 t and carries a working load of 55 t. It is moved by a diesel- or battery-driven locomotive. However, a further plateau transporter is available with a lower load of 25 - 30 t for emplacing waste.

The only railless machine capable of picking up a package and transporting it independently is the emplacement machine. For reasons of redundancy, two emplacement machines are available. Their motor and brakes are designed for transporting packages over ascending and descending gradients of up to 1 %. The emplacement machines are not able to transport packages over sloping tunnels with a gradient of 10 - 12 %. The final design of the emplacement machines has not yet been decided. Two concepts are being discussed, on the one hand an articulated shovel loader with fork, also known as the Kiruna truck, and alternatively a portal lift truck on four stilts as e.g. used for container transport.

### 2.2.5 Ventilating the Geological Repository

Fresh air is brought in via the debris transport shaft to the emplacement floor and is then fed into the emplacement and advance working operations via the access gallery. The emplacement tunnels receive special ventilation via air ducts during advance working and emplacement. Outgoing air is fed directly to the former exploratory floor via ventilation chutes at the ends of the connection drifts and is then directed to the emplacement shaft where it escapes. Package transport on the emplacement level also takes place in the fresh air flow. A monitoring of the exhaust air for radioactivity is envisaged at least for the exhaust shaft.

# 3 NP ASPECTS OF DIRECT FINAL DISPOSAL

## 3.1 Direct Final Disposal in Comparison to Waste Management by Reprocessing

### 3.1.1 Consequences of a Direct Final Repository as a Model for Third Countries

From the proliferation point of view there are two areas in the nuclear fuel cycle requiring special protection:

On the one hand there are the two sensitive steps of enrichment and reprocessing whose technologies can in principle be used to separate strategic nuclear material, and on the other hand the accumulation of sensitive nuclear material for example in storing separated plutonium or spent fuel elements.

The protection and control of sensitive technology is the subject of the London Guidelines in which the individual components to be protected are listed in detail. A possible abuse of the facilities themselves is covered by the various international safeguards agreements with the IAEA within the framework of the NP Treaty or bilateral agreements.

An accumulation of spent plutonium can result in a fuel cycle with reprocessing for example by delaying the expansion of nuclear energy programmes, e.g. for breeder reactors. Institutional models have already been developed based on Article XII A5 of the IAEA Statute envisaging an international plutonium storage system for excess separated plutonium. Amongst other aspects, storage of excess plutonium is envisaged as well as a reduction in the storage capacities at fuel element factories for reactor fuels containing plutonium.

The accumulation of plutonium in the intermediate storage of spent fuel elements has also been identified as a sensitive point in the nuclear fuel cycle. The ISFM Group, meeting within the framework of the IAEA, has suggested appropriate countermeasures /3-1/.

The accumulation of plutonium in direct final disposal is regarded as especially disturbing in many quarters with respect to the non-proliferation of nuclear weapons. In this connection the concept of a "plutonium mine" has been introduced /3-2/. Particularly on the part of the Europeans and Japanese, the inherent proliferation danger at such final repositories was pointed out at the International Nuclear Fuel Cycle Evaluation Conference (INFCE) since in principle later access by a state to the very large quantities of plutonium which would be present in a geological repository with spent fuel elements can never be ruled out. This is of special significance because access to the plutonium will become easier in the long term due to the decreasing radioactivity of the spent fuel elements and thus the strategic value of the material will increase.

In connection with the large quantities of stored plutonium and the long operational life of such a repository of approx. 50 years, it must be pointed out that notice to or termination of the NP Treaty cannot be ruled out in various countries. In this case the state thus has the legal possibility of excavating spent fuel elements from the direct final repository and separating the plutonium for atomic weapons. It can be assumed that notice to the NP Treaty by the Federal Republic of Germany is out of the question.

Furthermore, it is not possible to waive the application of safeguards for a certain quantity of nuclear material on the basis of bilateral agreements. On the basis of these bilateral agreements it could rather result that the contracting parties would be able to participate in formulating safeguards application in the long term, which could lead to a tightening of safeguards (prior consent). On the basis of these overriding proliferation aspects it seems difficult to discuss the establishment of such repositories as a model for worldwide application since other states without the appropriate contractual conditions for controlling non-proliferation (non-proliferation credentials) would be in a position to obtain long-term access to sensitive plutonium.

In examining the question of the extent to which a non-recoverability concept would hinder later access to sensitive plutonium it must generally be presumed that in principle there will always be technical possibilities of bringing an emplaced fuel element back into the light of day. The technical difficulties depend, amongst other aspects, on the final disposal medium and they are probably greater for disposal in salt than for other media. It must be remembered that not all countries have this storage medium available and thus different proliferation profiles would result in the corresponding countries. The unusually large quantities of plutonium would make it possible to create large nuclear programmes for atomic weapons.

### 3.1.2 Possibility of Terminating Safeguards

The criteria for terminating IAEA safeguards are laid down in Paragraphs 26(C) of INFCIRC/66 and 11 of INFCIRC/153 corresponding to Art. 11, Verification Agreement (VA):"...upon determination by the Community and the Agency that the material has been consumed, or has been diluted in such a way that it is no longer usable for any nuclear activity relevant from the point of view of safeguards, or has become practically irrecoverable" /3-3, 3-4/.

The conditions of Paragraph 11, INFCIRC/153 are thus not applicable to spent nuclear fuel. The INFCE Working Group 7 established in their concluding report /3-5/ that waste from the LWR fuel cycle (recycled and non-recycled) is relatively unattractive for weapons production. Depleted uranium must either be enriched or irradiated and reprocessed. Pu waste is difficult to recover because of the great dilution in glass or cement. In the opinion of the INFCE, both types of waste probably correspond to IAEA criteria for terminating safeguards.

Since it becomes easier to handle spent FE's from the LWR cycle without recycling due to decreasing fission product activity, this is the type of waste in the LWR fuel cycle which, according to INFCE, is more attractive with respect to diversion. The easier recovery of fissionable material by reprocessing is in contrast to the fact that in a final repository in salt recovery of the final disposal package in the course of time will not be made easier in the foreseeable future due to the high temperatures occurring in the long term.

The extent to which future technologies will alter this assessment does not only depend on the development of highly sophisticated technologies for the enrichment and recovery of recycled nuclear material but also on technical progress in mining engineering. At this moment in time, the question of long-term safeguardability arises in connection with the direct final disposal of spent nuclear fuels in a suitable geological formation. The essential aspects for terminating safeguards, as well as for long-term safeguarding, are listed in Table 3-1.

| Termination of Safeguards | Long-Term Safeguards |
|---|---|
| Non-Recoverability (not fulfilled without further provision) | Novel Problem |
| Degree of Dilution of the Fissionable Material | Cancellation of Membership in the NP Treaty |
| Solution Pursuant to INFCIRC/153, Paragraph 35 or VA, Art. 35 Conceivable for Such Types of FE Not Envisaged and Not Economic for Reprocessing | Duration of the NP Treaty until 1995 |
| | NP Credibility |
| | Model Character of the Direct Final Repository |

**Table 3-1: Termination of Safeguards Measures and Long-Term Safeguards: Essential Aspects**

### 3.1.3 Considerations on a Final Repository for HAW and Spent Fuel Elements

For certain kinds of spent fuel elements (e.g. AVR, THTR or special types of light-water reactors) reprocessing is either not envisaged or not economical. For such fuel elements direct final disposal is therefore necessary. The question thus arises whether a termination of safeguards can be possible for such nuclear material. If the quantities of spent fuel elements were to be small in relation to highly active waste, which would also be taken into the final repository, then - although the conditions of Paragraph 11 are not fulfilled - Paragraph 35 of INFCIRC/153 or Art. 35 VA could come into effect, which says:

> "...Where the conditions of that paragraph are not met, but the State considers that the recovery of safeguarded nuclear material from residues is not for the time being practicable or desirable the Agency and the State shall consult on the appropriate safeguards measures to be applied. It should further be provided that safeguards shall terminate on nuclear material subject to safeguards under the Agreement under the conditions set forth in paragraph 13 above, provided that the State and the Agency agree that such nuclear materil is practicably irrecoverable."

A termination of safeguards is therefore not impossible in principle, an application of simplified safeguards is conceivable at any rate.

### 3.1.4 Extrapolation of IAEA Discussions on Sensitive Facilities to a Direct Final Repository

Recent discussions at the IAEA in connection with the implementation of safeguards concepts for sensitive facilities in reprocessing and enrichment have indicated that concepts making intensive use of containment/surveillance systems are not acceptable /3-6/. Since precisely this conception with intensive C/S could be of essential significance in the case of a direct final repository, a conflict can be expected here. The IAEA would have to make considerable cuts and reorientations in their previous safeguards philosphy if this problem is to be solved. Only a few problems can be mentioned here such as design verification, availability and reliability of instruments, verification of nuclear material in the case of instrumentation failure, internal diversion etc.

In spite of all these difficulties it must be seen that pursuant to the safeguards agreement, e.g. INFCIRC/153, all nuclear facilities, such as a direct final repository for spent fuel elements, would in principle have to be internationally safeguardable. However, in this case, considerable cuts would have to be made for such a safeguards concept in the "effectiveness" demands as currently discussed at the IAEA.

### 3.2 Results of NP Discussions in INFCE

Since about 60 nations and various international organizations, such as the IAEA, participated in INFCE the results and considerations of this conference are of particular significance for further approaches. This is especially true since the numerous previous discussions were combined and extended at INFCE. Thus INFCE Group 7 "WASTE MANAGEMENT AND DISPOSAL" concerned itself with the problems of safeguards in final repositories for spent fuel elements, the salient points of which will be given in the following.

Only waste containing U-235, U-233 and plutonium is of significance from a safeguards point of view. Other transuranic elements, such as neptunium and americium could also be of significance in future. Depending on their content of nuclear material the following categories of waste are differentiated in the INFCE considerations:

(I) Waste in the form of depleted uranium, natural uranium or low enriched uranium ( < 20 % U-235), so-called non-HEU waste.

(II) Highly active waste containing plutonium (or U-233 in the thorium cycle) and U-235.

(III) Waste with a low plutonium content and low content of high-enriched uranium, so-called HEU waste.

Spent LWR fuel elements thus fall into waste category (II). The flow of nuclear material in the fuel cycle can be quantified from the safeguards aspect with the aid of the concept of the "significant quantity". In the case of uranium waste in category (I), the significant quantity is 75 kg of U-235. In the case of plutonium and HEU waste the significant quantities are 8 kg for plutonium and U-233, and 25 kg for U-235. ( ≥ 20 %). These values also correspond to the guidelines for target quantities suggested by the IAEA. If one finally also considers that the waste is generally not present in the form of an open flow but rather packed in containers then the concept can be meaningfully characterized as "target batch". This is taken as the number of waste containers which together contain a significant quantity of nuclear material. In the case of LWR fuel, two spent fuel elements form a target batch.

The most attractive target for a diversion of nuclear material is represented by the spent fuel from the light-water reactor once-through cycle in the waste categories under consideration. The high radioactivity of the fission products initially functions as a self-protection for the fuel, thus making handling of the material more difficult. Moreover, reprocessing technology is required to separate the fission products and actinides, as well as to separate uranium and plutonium. However, after a correspondingly long storage period the radioactivitiy is significantly reduced and access to the plutonium after recovery becomes easier. Nevertheless, if the spent fuel elements are at that time enclosed in suitable containers in a final repository deep in the geological substratum at a salt temperature of 120°C then this makes recoverability and thus access to plutonium more difficult.

The remaining types of waste in category (II), as well as the waste in categories (I) and (III) do not represent attractive diversion targets in the view of INFCE. Safeguards measures for spent nuclear fuel in a final repository consist of accountancy and verification from the time of unloading from the reactor until emplacement in the salt dome or a different geological formation. The monitoring of loading and unloading activities by inspectors and/or television units is currently state of the art of IAEA safeguards. The automatic safeguarding of fuel movements in a repository is currently being developed, in the same way as non-destructive analysis (NDA) for determining the fuel burn-up or plutonium content.

All processes from storing spent fuel until emplacement in the final underground repository are safeguards-relevant. According to the INFCE discussions, the following demands must be made:

(1) Surveillance of final disposal canister loading, item counting of the fuel elements changing to item counting of the final disposal packages. A tamper-resistant seal on the FDP would be able to detect attempts at breaching the integrity of the package;

(2) counting the fuel elements or final disposal packages before and after each transport step;

(3) containment/surveillance and verification of the FDP from receiving the package until emplacing it in the final repository;

(4) containment/surveillance in order to ensure that there is no material retransport (possibly supported by monitors to detect the movements of radioactive material);

(5) inspections to verify the plant design in order to rule out the existence of clandestine transport paths, stores or equipment.

Three phases can be differentiated in safeguards measures with respect to a direct final repository:

During the first, or active, phase of the geological repository, item counting, inventory verification and surveillance are applied.

The second, or passive phase begins when individual areas of the repository are filled in again after emplacing the final disposal packages. Since during this phase recovery of waste becomes increasingly more difficult due to the filling in and the associated enlargement of the containment, the safeguards activities would be shifted from item counting to containment/surveillance after agreement between the IAEA and the operator.

The third, or post-operational phase, begins with the closure of the geological repository. It must be established by surveillance measures and periodic inspections of the area in question that no attempts at recovery have been undertaken.

After deactivating the final repository the degree of safeguards measures will be able to be reduced according to the concluding report of INCFE Working Group 7, pages 101 and 102, namely for the following reasons. Assuming there was an incentive to recover nuclear material from the shut-down repository if a considerable fraction of the emplaced nuclear fuel were to be recovered then this would practically mean reactivating the geological repository, associated with considerable efforts: drillings, shaft construction, ventilation, transport of excavated material, canister transport etc. In this case it would take 12 - 18 months before nuclear material would begin to emerge from the final repository. Such an undertaking would thus be easily observable. On the other hand, analyses have indicated that the recovery of a few final disposal canisters would be possible within a brief period (8 - 10 weeks). However since even for this undertaking, whose costs would amount to roughly $ 25 million, several large drilling facilities would be required which could hardly be concealed. This is, however, not directly transferable to the reference concept since in the analysis quoted in the INFCE report studies were undertaken for a final disposal canister 35 cm in diameter. Several of these canisters would therefore be required for a significant quantity of nuclear material.

In the long term the effectiveness of safeguards measures is questioned by INFCE (Concluding Report Group 7, page 101) since the post-operational phase lasting for centuries will be determined by numerous, hardly foreseeable factors such as:

- alterations in the institutional and social system,
- large inventory of fissionable material in repositories for spent FE's,
- decrease in radioactivity and thus better possibilities of recovering the fissionable material,
- development of new technical safeguards measures (i.e. processes and equipment),
- possible technological developments to accelerate the recovery of very diluted waste,
- degree of integrity of canisters with spent FE's in shut-down geological repositories and possibilities of recovery,
- later incentives for recovering the fissionable material from spent fuel for energy generation purposes.

No detailed predictions can be made about most of these factors. It is therefore not possible from current perspectives to make a decision on the possibility of monitoring a direct final repository in the post-operational phase or terminating safeguards.

# 4 APPLICATION OF IAEA SAFEGUARDS REGULATIONS TO THE REFERENCE CONCEPT

## 4.1 Political and Technical Boundary Conditions

### 4.1.1 Legal Bases for Safeguards

In the Federal Republic of Germany the tasks of international nuclear material safeguards - conditioned by the commitment to the European Atomic Energy Community (EURATOM) and the Non-Proliferation Treaty (NP Treaty) - are undertaken by two institutions:

- the Commission of the European Communities and
- the International Atomic Energy Agency (IAEA).

#### 4.1.1.1 The EURATOM Treaty

The objective of the treaty establishing the European Atomic Energy Community is a common market in the sector of the peaceful uses of nuclear energy; the major aspects being of equal priority in the assured supply of ores and nuclear fuels, promotion of research and the non-proliferation of nuclear weapons. The following boundary conditions can be derived from the EURATOM Treaty /4-1/ for direct final disposal:

- The material in the final disposal packages is special fissionable material and property of the European Atomic Energy Community.
- The Commission of the Community is obliged to safeguard the material with the aim of convincing themselves that it is being used for no other purposes than those specified by the users.
- The Commission inspectors shall have access to all locations, documents and persons related to the use or storage of nuclear material at all times.
- A purely national solution to the problem of the direct final disposal of spent fuel elements cannot be derived from the articles of the EURATOM Treaty quoted in detail in the following.

The aims and procedures of nuclear material safeguarding by the Commission of the European Communities are specified in detail in Chapter VII of the EURATOM Treaty. Safeguards are accordingly based on nuclear material accountancy, reports to EURATOM and the unimpeded access of EURATOM's inspectors to all nuclear facilities.

Pursuant to Art. 79 it is incumbent upon the operator of a nuclear facility to keep and present records of operational processes in the utilization or generation of materials subject to safeguards, thus enabling account to be kept of these materials. This is also valid for transportation of these materials. Whoever shall erect or operate a nuclear facility must inform the Commission of the plant design, insofar as this is necessary for the Commission to fulfill its tasks (Art. 78). The tasks of the Commission arise in part from Art. 77. Pursuant to this, it must ensure by appropriate safeguards:

- that the nuclear materials are not used for any purposes other than those envisaged;
- that the regulations concerning supply and all special safeguards obligations (prior consent) undertaken by the Community are observed.

The safeguards comprise ores, source materials and special fissionable materials. Pursuant to Art. 81 the Commission inspectors shall have access to all places and data and to all persons professionally concerned with materials, articles of equipment or facilities subject to safeguards at all times.

Article 86 says:

Special fissile materials shall be the property of the Community.

The Community's right of ownership shall extend to all special fissile materials which are produced or imported by a Member State, a person or an undertaking and . . . are subject to safeguards.

Whereas the proprietary rights of the Community to all special fissionable materials are laid down in Chapter VIII (Art. 86), Chapter VI regulates the supply of the member states with ores, source materials and special fissionable materials:

- In order to ensure a common supply policy according to the principle of equal access to the sources of supply, an agency was established to direct rights to the materials mentioned above generated on the territory of the member states. It has the exclusive right to conclude contracts on the supply of these materials from countries within and without the Community. (Art. 52).

- Pursuant to Art. 57, the rights of the EURATOM Supply Agency comprise the acquisition of

  a) rights to the utilization and consumption of special fissionable materials and

  b) proprietary rights in all other cases.

- Pursuant to Art. 62, Subsection 1, the Agency exercises its rights to the special fissionable materials generated in the member states in order to:

  a) cover consumer demand

  b) store these materials itself or

  c) export them.

In Art. 62, Subsection 2 the possibility is conceded of leaving these materials and the residues suitable for reprocessing with the producer so that they can be stored with the consent of the Agency. Furthermore, attention should be drawn here to Art. 80 of Chapter VII (Safeguards) according to which the Commission may demand that all excess special fissionable materials be deposited at the Agency or in other repositories subject to safeguards.

### 4.1.1.2 Effects of the NP Treaty

In order to fulfill the obligations of the Non-Proliferation Treaty the non-nuclear-weapons states of the European Atomic Energy Community concluded an agreement (Verification Agreement) with the IAEA and EURATOM in 1973. This agreement (VA) essentially corresponds to the IAEA standard agreement INFCIRC/153. The basis for safeguards in the sector of the peaceful uses of nuclear energy is created for the nuclear weapons states of the Community by corresponding agreements.

Subsidiary Arrangements are appended to the Verification Agreement in which, amongst other aspects, inspection activities and efforts are determined on a model basis. The Verification Agreement and the Subsidiary Arrangements have the character of treaties concluded between the states, EURATOM and the IAEA, in which EURATOM and its member states undertake obligations to the IAEA. In order to be able to fulfill these obligations EURATOM adapted its safeguards system to the new requirements. This was implemented by directive no. 3227/76 /4-2/ replacing the old directives no. 7 and no. 8.

The Subsidiary Arrangements comprise the Facility Attachments separately compiled by EURATOM and the IAEA for each nuclear facility. These Facility Attachments (FA) are the basis of the special safeguards provisions determined by EURATOM for each facility.

### 4.1.1.3 Safeguarding by IAEA and EURATOM

EURATOM undertakes safeguards in the nuclear facilities of the Community pursuant to the EURATOM Treaty and EURATOM directive no. 3227/76. IAEA safeguards are based on the NP Treaty and the Verification Agreement. Details of this implementation are determined in the Subsidiary Arrangements and the Facility Attachments (FA). The EURATOM special safeguards provisions transfer safeguards based upon the FA to the EURATOM level, insofar as these measures are not already determined by the EURATOM directive.

EURATOM and IAEA cooperate in detecting possible diversions of nuclear material for nuclear explosive devices. To this end

- in discussing the FA, EURATOM communicates the facility data provided by the facility operators to the IAEA with the exception of information to be commercially protected,
- EURATOM communicates to the IAEA in a modified form the reports on nuclear material it has received from the operators of the nuclear facility,
- the IAEA obtains the right to monitor part of EURATOM's inspections.

The IAEA verifies the results of EURATOM's safeguards insofar as these are implemented on the basis of the Verification Agreement and the FA's. The following principles are valid for the IAEA verification activity (see also Table 4-1):

1. The concept of preventing diversion used in the NP Treaty is restricted to the timely detection of a diversion and the deterrent effect.

2. Restriction of safeguards to nuclear material, i.e. the facilities themselves are not monitored.

3. Principle of applying safeguards only at certain strategic points in the flow of fissionable material.

4. Restricting the IAEA to verifying the results of the EURATOM safeguards system.

5. Application of safeguards in such a way that the economic and technical development in a state or international cooperation in the field of nuclear energy is not impeded.

6. In certain cases substantiated by the IAEA, it shall obtain the right to undertake its own independent special inspections.

| |
|---|
| Preventing diversion by a deterrent effect (timely detection) |
| Nuclear material safeguards (not: facility safeguards) by measurements as well as containment/surveillance |
| Strategic points principle |
| Verification of EURATOM results (reports) |
| No impediment to the peaceful uses of nuclear energy |
| Right to own independent inspections |

**Table 4-1: Principle of IAEA Safeguards Pursuant to the Verification Agreement**

4.1.2 Boundary Conditions for Implementing Safeguards

On the basis of the principles described above, the following problem areas result as boundary conditions for the development of the safeguards concept:

4.1.2.1 By EURATOM

1. Clarification of the question of the extent to which the unrestricted utilization and consumption rights of a member state exercised on the basis of possessive rights to nuclear material (Art. 87) are restricted by the proprietary rights of the Community. It must be assumed that in the case of final disposal conceived of as non-recoverable this decision on disposition must be regarded as irreversible and thus requiring at least the consent of the Community as the owner of the material. Various models are conceivable in which the owner and the possessor share responsibility for and implementation of final disposal, e.g.:

- The Community declares that it does not regard its proprietary rights as impaired by the non-recoverable final disposal of the material and cedes responsibility for and implementation of final disposal to the member state.

- The member state implements national final disposal on behalf of the Community, whereby conditions must be expected to be imposed by the Community.

- Final disposal is carried out as a multinational undertaking by the Community itself, the member state making territory and infrastructure available (cf. Art. 80, Deposition).

Variant 1 underestimates the long-term proliferation aspects of a direct final repository. In this case the interest of the Community does not concentrate on proprietary rights but rather on effective safeguards.

Variant 2 corresponds most closely to the interests of the Federal Republic of Germany. Retention of ownership and safeguards is ensured on the part of the Community and is internationally verifiable. A national final repository is also more advantageous from the point of view of acceptance than

Variant 3. This includes the possibility of a final disposal of foreign final disposal products from EURATOM states and thus presents significant acceptance problems. In view of the geographical and political situation of the Federal Republic of Germany, Variant 3 cannot be desirable.

2. EURATOM requirements with respect to nuclear material accountancy and the report system are largely in agreement with IAEA demands.

3. With respect to regulations for inspection activities, EURATOM's inspection rights are comprehensively determined in the EURATOM Treaty Art. 81.

4.1.2.2 By IAEA

The position with respect to IAEA safeguards must be considered in much more detail. The following problems are to be discussed and clarified on the basis of the Verification Agreement:

1. Quantification of timeliness of detection and significance of nuclear material quantities.

2. Determination of strategic points with clarification of access rights for IAEA inspectors.

3. Clarification of the problem of the extent to which the IAEA can implement safeguards independently of EURATOM.

4. Clarification of the question of the extent to which safeguards can be terminated if proof of non-recoverability of the material is furnished.

These points will in part only be finally determined in the Facility Attachments, however they must be considered in the safeguards concept of the facility.

Re 1: Quantification of timeliness of detection and significance of nuclear material quantities.

The IAEA detection goals are described by the following parameters still to be quantified:

- significant quantity
- timeliness of detection
- detection probability of a diversion
- probability of false alarms.

The quantification of these variables, as well as the total inventory and its strategic significance, serve the IAEA as a basis for developing its safeguards model for the facility to be safeguarded. In implementing the model for a specific facility, the inspection goals aimed at for the facility in question will be derived from these detection goals.

The detection goals depend greatly on the type and composition of the material to be safeguarded. If one bases the products for final disposal on LWR fuel elements of the Biblis type then the data listed in Table 4-2 result for the irradiated FE's.

| Fissionable Materials | FE | FDP | Annual Increment of the Final Repository | Total Inventory of the Final Repository after 50 Years |
|---|---|---|---|---|
| U-235 | 4.1 kg | 12.3 kg | 5.4 t | 268 t |
| Pu-239 | 3.1 kg | 9.3 kg | 4.0 t | 201 t |
| Pu-241 | 0.4 kg | 1.2 kg | 0.6 t | 11 t |
| Total | 7.6 kg | 22.8 kg | 10.0 t | 480 t |
| | | | | |
| Uranium | 506.0 kg | 1518.0 kg | 663.0 t | 33,140 t |
| Plutonium | 5.3 kg | 15.9 kg | 7.0 t | > 212 t |
| Fission Products | 22.0 kg | 66.0 kg | 28.8 t | |

**Table 4-2: Final Repository Inventory of Spent FE's /4-3/**

The variables currently set as guidelines by the IAEA for significant quantities (SQ) are 8 kg for plutonium and 75 kg for low enriched uranium U-235; that means that each final disposal package contains more than the significant quantity of plutonium.

Bulk handling facilities (BHF) are classified by the IAEA according to a nuclear material index (NMI). This is based on the facility throughput or the facility inventory, expressed in weighted significant quantities (WSQ). The inspection and verification activities of the IAEA are concentrated on facilities with a high nuclear material index. In the Safeguards Implementation Report (SIR) for 1981 the following statistical maximum values are given for the safeguarded BHF's in order to characterize the spread:

- max. plutonium inventory (in significant quantities) 137
- max. annual plutonium throughput (in significant quantities) 167

In the case of a direct final repository these values would already be considerably exceded in the first year of operation, as can be seen from the following summary of significant quantities:

| Pu | U | |
|---|---|---|
| 2 | 0.16 | Final Disposal Package |
| 875 | 71 | Annual Increment of the Final Repository |
| > 26,500 | 3573 | Total Inventory of the Final Repository after 50 Years |

Simply from the quantity of material to be safeguarded, the final repository represents a new dimension for safeguarded facilities.

The IAEA does not specify any fixed value for detection time. It is aimed to achieve a timeliness goal of three months in the case of storage ponds for spent fuel elements in LWR facilities containing the same kind of fuel elements. It would have to be possible to take over this value for the final repository.

With respect to the probability of detection, a value between 90 and 95 % is usually aimed at, the probability of false alarm being assumed as smaller than or equal to 5 %.

However, a probability of false alarms of approx. 5 % is not acceptable for the final repository. On a computational basis this would mean 10 false alarms during the operating time with an inspection period of three months and a repository operating life of 50 years. It must be assumed that in the case of a final repository the clarification of a false alarm, i.e. the reopening of tunnels already filled in, is impossible or only possible with unjustifiably high expenditure. The fact that the material is no longer accessible to direct verification, or only with excessively great efforts, requires that a safeguards system for the facility be

a) resistant to failure and

b) resistant to false alarms.

This can probably only be achieved by an appropriate redundancy in safeguards measures.

Other materials which could be considered for direct final disposal are e.g. fuel elements from thorium high-temperature reactors. Reprocessing of these fuel elements is not currently envisaged or economical. A reference concept is currently being developed for the disposal of these fuel elements.

Re 2: Determination of strategic points with clarification of access rights for IAEA inspectors.

In accordance with the concept of the Verification Agreement, nuclear material safeguards are based on the principle of material accountancy and material balancing, as well as auditing and material verification:

- the facility operator keeps account of the changes in reserves and the reserves of nuclear material in his facility and prepares a balance sheet at at least annual intervals.

- Inspectors from the safeguards organizations examine the balance sheet and verify the data recorded in it.

The locations where data are verified and the locations where containment and surveillance measures are implemented are termed strategic points. It is a basic principle of nuclear material safeguards pursuant to the Verification Agreement that the activities of the IAEA inspectors and their rights of access are normally limited to the strategic points in the facilities. With respect to the inventory and verification of reserves, the safeguards model is based on assumptions of significance for practical implementation. The most important is:

During inventory taking all batches of nuclear material are to be presented at the key measurement points determined for the inventory, irrespective of the quantity of nuclear material they contain so that they can be verified by the safeguards organization. The verification is generally restricted to identification and visual checking of all batches and random measurement of individual batches.

Verification can either be direct, i.e. by verifying the values specified by the operator by means of measurements, or indirect, e.g. by examining attached seals and verifying the containment.

This basic safeguards model can only be technically applied to a very limited degree in the final repository. As soon as the final disposal canister is packed in or the tunnel is filled, a direct verification can no longer be technically implemented so that this basic model meets with considerable restrictions when applied to the direct final repository. Inventory taking is therefore only possible indirectly, for example according to the following pattern:

If there are no indications that the material is no longer there, then it can be concluded that it is still present and the results of the last verifications are therefore still valid.

This form of indirect material verification can only be acceptable for the safeguards authority if they can assume that all conceivable diversion pathways are safeguardable with sufficient reliability. To this end additional strategic points will have to be defined.

According to the definition of the Verification Agreement (Art. 98) strategic point means a location selected in assessing facility data where under normal conditions and in conjunction with information from all the strategic points necessary and sufficient information for implementing safeguards is accessible and can be verified; a strategic point may be a location where key measurements for material accountancy are implemented and where measures for containment and surveillance are undertaken.

Emplacing spent fuel elements only represents a small fraction of the handling processes in the final repository. Apart from the emplacement of fuel elements, it is envisaged that radioactive waste will also be deposited in the geological repository. Waste emplacement is in all cases independent of FDP emplacement, although the facilities above ground and the shaft equipment is used for both emplacement materials. Waste materials are delivered in barrels of 200 or 400 l with concrete shielding. It is envisaged that approx. 27,500 packages will be emplaced per year. Waste packages will be emplaced simultaneously with the FDP's. The same mining machines will be used for developing the waste emplacement field. There is no difference in the machines for the two fields. Waste packages are no longer subject to safeguards. Their emplacement need not be safeguarded.

However, the simultaneous and adjacent emplacement of radioactive waste must be regarded as an interference factor from the safeguards aspect. Due to waste emplacement, non-safeguarded activities not subject to disclosure are implemented above and below ground which could make detection of a diversion more difficult or facilitate concealment of a diversion. In order to develop a safeguards concept and determine the strategic points and the IAEA inspectors' rights of access it is therefore essential that all activities in the geological repository can be clearly differentiated by the safeguards authority. Due to the necessity of having to verify the material indirectly the completeness of their information with respect to all activities regarding material is of paramount importance for the safeguards authority. The safeguards authority can only state that they have no indications that the material to be safeguarded is no longer present if no activities requiring explanation or open to misinterpretation have been recorded in the vicinity of final disposal package emplacement. This can possibly lead to surveillance and access rights having to be granted to IAEA inspectors for processes, facilities and locations of waste emplacement in order to make all relevant activities at the geological repository transparent to them.

Re 3: Clarification of the question of the extent to which the IAEA may implement safeguards independently of EURATOM.

The Verification Agreement determines that EURATOM and IAEA shall avoid any unnecessary duplication of work in implementing safeguards. The IAEA implements safeguards activities in such a way that, insofar as it can achieve the objectives of its inspections, it monitors the activities of the EURATOM inspectors and verifies EURATOM's assessments. Apart from other aspects, the IAEA's verifications include independent measurements and surveillance. Considering the order of magnitude of the safeguards problem it is to be assumed that the IAEA will strive for the greatest possible independence from EURATOM's safeguards activity. This could mean e.g. that C/S measures would be applied redundantly for EURATOM and IAEA, or jointly evaluated, as is currently the case e.g. in camera monitoring in LWR facilities.

Re 4: Clarification of the question of the extent to which safeguards may be terminated if proof of non-recoverability of the material is furnished.

The criteria for releasing material from safeguards are described in Art. 11 of the Verification Agreement: "Safeguards under this Agreement shall terminate on nuclear material upon determination by the Community and the Agency that the material has been consumed, or has been diluted in such a way that it is no longer usable for any nuclear activity relevant from the point of view of safeguards, or has become practically irrecoverable."

With respect to evaluating non-recoverability, the type of emplacement is undoubtedly of decisive significance, and the emplacement envisaged in the reference concept with lost shielding makes it considerably more difficult to classify the material as "non-recoverable".

The operational phases of the repository must also be considered in evaluating recoverability. In view of the envisaged emplacement with lost shielding it will probably be very difficult to provide evidence that the material is already non-recoverable in the operational phase of the final repository, i.e. after the individual emplacement tunnels have been filled in.

Evaluation of recoverability in the post-operational phase of the repository, i.e. after the shafts have been filled in, must undoubtedly be regarded in a different light. If the material were still to be classified as subject to safeguards even in the post-operational phase of the repository then this would require safeguards for an unforeseeable length of time. This also represents a completely new dimension for international safeguards which in the case of conventional facilities can generally be terminated with removal of the inventory or at the latest with closure or decommissioning of the facility. Safeguards ad infinitum would probably also require new safeguards techniques which still have to be developed.

### 4.1.3 Current Discussion

It is generally accepted that a safeguards concept on the basis of INFCIRC/153 requires further development, at least for certain types of facility. An extended safeguards concept has been compiled by the IAEA which, over and above the existing model, envisages additional strategic points in the material balance areas at which operational records will be kept by the operator and measurements on nuclear material implemented by the inspector, as well as observations of operational processes in progress. The implementation of safeguards according to this model which has been included in some facility attachments for nuclear facilities in the Federal Republic has only been accepted on the part of the Federal Republic on a trial basis and for a limited period. This is especially true of the IAEA demands for:

- establishment of additional strategic points to determine the flow of nuclear material within material balance areas
- access to operational records concerning the flow of nuclear material at the additonal strategic points
- execution of verification activities at the additional strategic points
- implementation of safeguards basically independent of EURATOM.

There is no statutory basis in the Verification Agreement for these safeguards activities accepted as a trial for a limited period of time.

## 4.2 Safeguards Concept

The total nuclear material inventory of the final repository is contained in individual identifiable items, the final disposal packages. The IAEA safeguards concepts for such facilities are based on item accountancy. Since in the case of final disposal packages there is no possibility of direct verification, e.g. by non-destructive assay methods (NDA), the following methods remain as applicable measures within the framework of nuclear material accountancy:

- item counting,
- item identification,
- verification of the integrity of the item.

It is assumed for the safeguard's concept of the final repository that the contents of the final disposal package have been verified in the conditioning facility before being placed in the bin. The final disposal package is subsequently sealed in the conditioning facility in such a manner that the validity of the final measurement can be extended for an unlimited period by verifying the integrity of the item. The data from this measurement are retained for the item as long as it is still subject to safeguards. After leaving the conditioning facility the material contained in the item is only verified by identity and integrity verification.

### 4.2.1 Final Disposal Canister

The final disposal package for the reference concept (three intact FE's per FDP) consists of four concentric shells:

- dry disposal bin
- canister body
- corrosion protection
- lost shielding.

The canister body and corrosion protection form the final disposal canister which is cast en bloc in a special process. The floor and lid of the FDC are screwed in and welded. The main aspect as far as safeguards are concerned is the external cladding, i.e. in the case of final disposal with lost shielding the subsidiary shielding of the FDP or in the case of borehole disposal the corrosion protection of the FDC.

A cast cylindrical body is used as the lost shielding, the bottom and lid of which are screwed in in contrast to the procedure in the case of the shells it encloses. Mounting points are envisaged in such a way that it is possible to seal the floor and lid openings. If electronic seals are to be applied then for their protection cavities or recesses are envisaged in which the seals can be mounted. As a back-up system for the sealing of the lost shielding a weldment verification of the corrosion protection (next shell underneath) can be envisaged. In the further considerations it is first assumed that the cast canister envisaged as the subsidiary shielding (the lost shielding) representing the external containment of a final disposal package, can be verified with respect to its integrity by visual checks and that the containment openings are protected by one or more seals verifiable in situ.

### 4.2.2 Nuclear Material Flow

The final disposal packages are transported via the public railway network of the Federal Railway. They are delivered in a type B flask designed for transport on public routes pursuant to the regulations. The incoming trucks are first parked in the buffer zone. Buffer capacity is designed for three working days, i.e. nine final disposal packages. The final disposal packages themselves are not yet accessible in the buffer zone since they are still in the transport flasks.

The trucks are driven from the buffer zone to the reloading area and the final disposal packages are drawn out of the flasks and loaded onto the rail-bound internal transport trucks (plateau transporter). The final disposal packages are transferred by means of a crane facility. The subsequent reception control procedure takes the form of a dose rate measurement, a wipe test, a visual check and registration. The integrity of the containment and seal of the lost shielding could also be verified. The plateau transporter is then driven to the shaft, loaded into the hoisting cage and transported to the emplacement level. At the emplacement level the plateau transporter is removed from the hoisting cage and driven to the emplacement tunnel. Underground rail-bound transport is terminated at the junction of the access gallery and the emplacement connection drift.

The final disposal package is then transferred from the plateau transporter to the emplacement machine, or taken up by the latter and (not rail-bound) driven to the emplacement tunnel. The canister is deposited by the emplacement machine at the emplacement location. After the filling material has been pneumatically packed the canister is no longer accessible. The material flow is shown diagrammatically in Fig. 4-1.

### 4.2.3 Preliminary Considerations on the Safeguards Concept

On the basis of the material flow sketched above, the following considerations can be established:

The individual final disposal packages can only be identified and verified after removal from the flask. This takes place after leaving the buffer store at the beginning of the emplacement process, immediately before reception control. It therefore does not seem to be meaningful to divide the facility into several material balance areas (MBA) (e.g. according to the criterion above ground/under ground). The material only resides above ground (buffer store) for a maximum of a few days and the establishment of a separate MBA for the area above ground would require additional identification and accountancy efforts without improving the safeguards possibilities. After reception checks, the emplacement of the final disposal packages is implemented as a continuous process without further intermediate buffering.

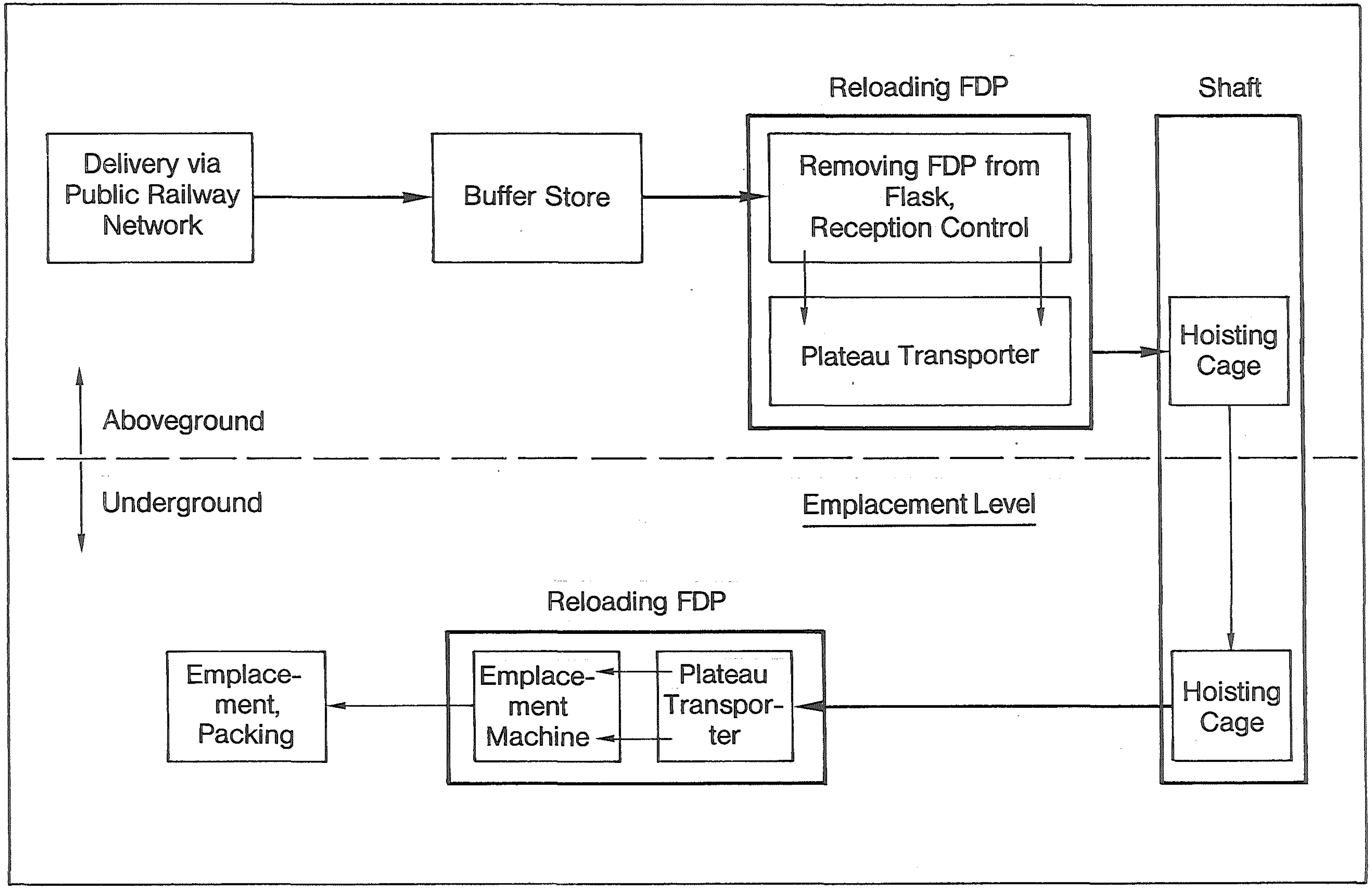



Figure 4-1 : Material Flow Diagram

The last opportunity of identifying a final disposal package is after it has been deposited in the emplacement tunnel by the emplacement machine. After this the filling process begins and this part of the tunnel becomes inaccessible. It should be examined whether this last step (packing the canister) can be coupled to an acknowledgement signal for the functionality of the safeguards devices in order to increase the system's resistance to failure.

As long as the emplacement process, including packing the final disposal package thus rendering it inaccessible, proceeds as a continuous process continuous safeguards are also required to verify the material flow. The objective of safeguarding the material flow is to verify whether the declared material has been emplaced at the declared location. The possibility of verifying the identity and integrity of final disposal packages already deposited in the emplacement tunnel and of only filling the tunnel under observation after all emplacement processes have been terminated could make an essential contribution to simplifying safeguards. In this case continuous safeguarding of the emplacement work could be replaced by batch-oriented verification (one or more complete tunnels) of the outcome of the work. However, it is technically more difficult to backfill the tunnel after completing all emplacement processes and leads to a considerably higher dose rate for the operating personnel due to direct radiation.

With respect to nuclear material safeguards, the first subtask will be to ensure that the material flow proceeds in the declared manner; i.e. that the declared material is transferred to the declared location. This can largely be achieved by applying surveillance measures (camera and/or human surveillance).

The next subtask consists of ensuring that the emplaced material remains at the emplacement location until its final containment (sealing the emplacement tunnel or tamping the access gallery for fields already backfilled). Surveillance measures could also be employed to prevent recovery of the material via declared paths.

Special measures are necessary for the final safeguards subtask, namely of ensuring that no further clandestine entrances can be created to the tunnels already backfilled and tamped via which the material could be diverted, or that the material could be subjected to clandestine further processing within the geological repository after the tunnels have been backfilled. This form of diversion would admittedly involve great technical efforts, however it cannot be reliably ruled out. Since no indicators are currently available or known for reliably indicating such a diversion, the strategy for this safeguards subtask must consist in increasing the technical efforts required for clandestine diversion via these paths by appropriate measures to such an extent that this diversion risk can be reduced to an acceptable residual risk. Suitable measures could for example be comprehensive access concessions to all aboveground and underground facilities for inspectors.

### 4.2.4 Safeguards Concepts for Different Access Models

Three models are to be considered in the following differentiated by different access rights for the IAEA inspectors. In Model 1 access is restricted to the aboveground facilities, Model 2 comprises limited access to the underground facilities and Model 3 unrestricted access to all underground facilities.

#### 4.2.4.1 Access Model 1

Version 1

In this model the inspector's access is restricted to strategic points above ground. Strategic points (SP) are the key measurement points (KMP), the aboveground unloading facility and both shafts to the geological repository.

The essential element in this model is that after transferring the material underground recovery or an internal diversion within the repository is ruled out. By transferring the material underground it is thus released from safeguards and written off via KMP 2 (exemption from compulsory registration). Since according to this model there is by definition no longer any material subject to safeguards present after terminating emplacement activities, no safeguards are required for the post-operational phase either. The essential elements of this model are:

material balance areas

- the facility forms one material balance area

strategic points, being key measurement points

- for determining the flow of nuclear material
  - KMP 1 - entry, intake, cancellation of exemption (for rework material)
  - KMP 2 - exemption from compulsory registration
- for physical inventory taking
  - KMP A - buffer store

records system

- accounting for inventory changes
  - entry, intake at the time of entry
  - exemption from the compulsory registration at the time of transfer underground
- operating records contain the following data
  - place and time of emplacement for each FDP
  - type, place and time of backfilling/sealing measures

installations and installed devices

- seals on FDP's
- optical surveillance of FDP unloading aboveground
- optical surveillance/detectors at the entrances to the two shafts

strategic points for containment and surveillance measures

- FDP unloading aboveground
- entrance shaft 1
- entrance shaft 2

recording the physical inventory

- counting and identifying the items at key measurement point A

Safeguards applied:

- pre-operational phase
  - design verification before startup (only above ground)
- operational phase
  - identity and integrity verification of the final disposal package by the inspector at the entrance (reception control)
  - camera monitoring at the aboveground unloading facility to prevent undeclared unloading processes (replacement with dummies)
  - C/S measures (camera, detectors) at the strategic points shaft 1 and shaft 2 to prevent undeclared material flow (backflow)
- post-operational phase
  - no safeguards

Version 2

Version 2 of this model is only differentiated by the fact that the material under ground cannot be released from compulsory registration. KMP B thus takes the place of KMP 2 for inaccessible material below ground. The inventory is taken at this key measurement point by establishing on the basis of observations at the strategic points Shaft 1 and Shaft 2 that no material backflow has taken place. The material brought into the repository must therefore still be present there. Safeguards in the post-operational phase depend on whether requirements for releasing the material from safeguards have been able to be fulfilled at the closure of the geological repository. The essential elements of this version of the model are:

material balance areas

- the facility forms one material balance area

strategic points being key measurement points

- for determining the flow of nuclear material
  KMP 1 - entry, intake
- for taking the physical inventory
  KMP A - buffer store
  KMP B - all underground facilities, material inaccessible

records system

- recording inventory changes
  - entry, intake at the time of entry
  - exemption from compulsory registration at the time of closing the geological repository if termination envisaged on the part of the IAEA
- operating records contain the following data
  - place and time of emplacement for each FDP
  - type, place and time of filling in/sealing measures

installations and installed devices

- seals on FDP's
- optical surveillance of FDP unloading above ground
- optical surveillance/detectors at the entrances to the two shafts

strategic points for containment and surveillance measures

- FDP unloading above ground
- access Shaft 1
- access Shaft 2

taking the physical inventory

- counting and identifying items at key measurement point A
- establishing that no return flows have occurred via the SP's Shaft 1 and Shaft 2; concluding that the material brought in must still be present.

Safeguards applied:

- pre-operational phase
    - design verification before startup (above and below ground)
- operational phase
    - identity and integrity verification of the final disposal packages by the inspector at entry (reception control)
    - camera monitoring at the aboveground unloading facility to prevent undeclared unloading processes (replacement by dummies)
    - C/S measures (camera, detectors) at the strategic points at the two shafts to prevent an undeclared material flow (backflow)
- post-operational phase
    - termination of safeguards after backfilling all shafts, decommissioning of the aboveground facilities as well as demonstration of non-recoverability (if acknowledged to be impossible by means of mining technology)
    - routine examination of the site by visual inspections to safeguard against activities which could indicate a reopening of the geological repository or other measures for recovering the material.

The two versions of this model assume that the final geological repository itself can be regarded as a sufficient barrier so that measures ensuring

- that there are no undeclared containment openings through which the material could be recovered and

- a diversion of the material within the containment (reprocessing below ground) can be ruled out,

can be dispensed with.

### 4.2.4.2 Access Model 2

This model comprises Model 1 and additional strategic points below ground. The strategic points below ground enable the inspector to safeguard the underground flow of material. Safeguarding the flow of nuclear material below ground can be undertaken at various levels of intensity:

- safeguarding the underground flow of nuclear material by camera monitoring and possibly recording instruments at the hoisting and transport installations with the possibility of human surveillance in the case of instrument failure,
- additional random human surveillance of emplacement processes,
- every final disposal package to be personally accompanied by the inspector from transport to the shaft until emplacement in the tunnel and backfilling of the tunnel section.

The same restrictions are largely applied to this model as to Model 1. It would have to be possible to terminate safeguards after backfilling the tunnel, or the final geological repository itself would have to be regarded as a sufficiently reliable barrier.

Access of the inspector to strategic points underground would admittedly considerably hinder a diversion in the final geological repository or out of the repository, however, it cannot be ruled out with sufficient reliability.

The essential elements of Model 2 are:

material balance areas

- the facility forms one material balance area strategic points being key measurement points

- for determining the flow of nuclear material
  - KMP 1 - entry, intake
  - KMP 2 - exemption from compulsory registration if safeguards termination envisaged on the part of the IAEA
- for taking the physical inventory
  - KMP A - buffer store
  - KMP B - tunnels not yet backfilled, underground
  - KMP C - backfilled tunnels, underground

records system

- recording inventory changes
  - entry, intake at the time of entry
  - exemption from compulsory registration at closure of the geological repository, if termination of safeguards possible
- operating records contain the following data
  - place and time of emplacement for each FDP
  - type, place and time of backfilling/sealing measures

installations and installed equipment

- seals on FDP
- optical surveillance of FDP unloading above ground
- optical surveillance/detectors at the entrances to the two shafts
- optical surveillance of FDP unloading below ground (pit bottom - access gallery, access gallery - emplacement connection drift and entrance to the emplacement tunnel)
- recording instruments / tachograph for the hoisting engine, plateau transporter (tractor) and emplacement machine (if available and necessary).

Strategic points for containment and surveillance measures

- FDP unloading above ground
- access Shaft 1
- access Shaft 2
- FDP unloading below ground (hoisting cage - access gallery and access gallery - emplacement connection drift)
- entrance to emplacement tunnel

taking the physical inventory

- counting and identifying items at the key measurement points A and B, if not yet backfilled
- integrity verification of the ends of the tunnels at key measurement point C by visual inspection; concluding that the emplaced material must still be present.

Safeguards applied:

- pre-operational phase
  - design verification before startup (aboveground and underground)
- operational phase
  - design reverification after driving a new tunnel
  - identity and integrity verification of the final disposal packages by the inspector at entry (reception control)
  - camera monitoring at the unloading facility above ground to prevent undeclared unloading processes (replacement by a dummy)
  - C/S measures (camera, detectors) at the strategic points at the two shafts to prevent undeclared material flow (backflow)
  - camera monitoring at the underground unloading points (from the hoisting cage on rails along the access gallery; from the plateau transporter on an emplacement machine without rails) to prevent replacement by a dummy
  - camera monitoring at the entrance to the emplacement tunnel to observe the emplacement process and prevent recovery until the tunnel has been sealed

- recording the duration and speed of run in the case of the hoisting engine, plateau transporter (tractor) and emplacement machine as back-up measures for camera surveillance (if available and necessary)
- inspector access to the strategic points underground either on a random basis or at any time.

- Post-operational phase
  - termination of safeguards after backfilling all shafts, decommission of the aboveground facilities as well as demonstration of non-recoverability (if recognized as impossible by means of mining technology)
  - routine examination of the site by visual inspection for safeguarding against activities which could indicate a reopening of the repository or other measures for recovering the material.

In the case of Model 2, the diversion possibility also remains as a residual risk e.g. of opening clandestine access to already backfilled tunnels or fields of the fuel element emplacement section from the waste emplacement area, diverting final disposal packages with a supplementary emplacement machine from the FE disposal area into the waste disposal area and either disguising them here as MAW, required for rework, for transport above ground, or further processing them in the waste section. Abuse of the waste disposal area for a diversion from the FE disposal area can be made considerably more difficult by permitting IAEA inspectors unhindered access to all facilities in the geological repository. This possibility is envisaged in Model 3.

4.2.4.3 Access Model 3

Model 3 comprises Model 2 and moreover also all underground facilities and installations as supplementary strategic points:

Strategic points for containment and surveillance measures

- all facilities and installations of the final geological repository, above and below ground, including the waste disposal area.

Safeguards applied (in addition to Model 2):

- operational phase
    - inspector access to all underground facilities (including the waste disposal area) on a random basis or
    - unrestricted inspector access to all underground facilities (including waste disposal area).

## 4.3 Safeguards Elements

### 4.3.1 Requirements

The final repository is a purely conventionally equipped disposal facility. Only conventional hoisting and transport installations are envisaged. All the nuclear material is contained in canisters in such a manner as to be handled conventionally. Facilities for handling, investigating or otherwise treating open irradiated material, such as e.g. hot cells, radiochemistry etc., are not envisaged. It is not technically possible to verify the contents of the FDP's in the final repository since all necessary preconditions are lacking. Reception control procedures of the package consist of recording, measuring the dose rate and a wipe test. All verifications over and above this with respect to form, quantity and composition of the nuclear material in the FDP, required on the basis of national and international safeguards regulations, must therefore be implemented before the FDP's are delivered to the final repository, i.e. in the conditioning facility.

A decisive element in designing the safeguards system is the fact that the FDP's neither change their form nor their composition nor their external appearance in the final repository. Solely changes in location of the nuclear material are implemented, in accordance with the precisely predetermined sequence model. The objective of safeguards is thus to ensure that the declared FDP is transported in the declared form (i.e. unaffected integrity) to the declared location and then remains there.

The following requirements are the starting point for the safeguards system:

1. The period between the last verification of an FDP in the conditioning facility and emplacement of this FDP in the final geological repository is less than the detection time required for the material so that an intermediate inventory verification is not required from the safeguards aspect.

2. A positive verification of the identity of the FDP and the integrity of its external cladding, i.e. the lost shielding, is a sufficient condition for the verification of the nuclear material contained in the FDP.

3. Continuous monitoring of the flow of packages can be dispensed with as long as the FDP remains accessible for this verification, or the inspector has access to the individual FDP's.

4. If the FDP itself is no longer accessible, or it is in areas to which the inspector does not have access, and verification by examining the identity and integrity is thus not possible, then safeguarding potential diversion paths is sufficient in order to be able to make a statement about the inventory of enclosed nuclear material.

Requirement 1 implies that the time required for transporting the FDP from the conditioning facility to the final repository and for emplacing the FDP is less than the detection period required for diverting the FDP material. No further verifications are thus required for reasons of timeliness of detection between the time of leaving the conditioning facility and the emplacement process. Transport monitoring possibly required for reasons of physical protection is not included in the safeguards concept.

Requirement 2 implies that all nuclear material data with respect to type, quantity, composition etc. required for the safeguards system have already been determined before transportation to the final repository. Verification of the nuclear material in the final repository is restricted to establishing that these previously determined data are still valid since there are no indications for a presumption to the contrary. These data are merely carried forward in the accountancy of the final repository.

According to Requirement 2, examination of the identity and integrity is sufficient to verify the nuclear material as far as safeguards are concerned. In the case of a positive result, the safeguards authority can conclude that no changes have arisen since the last verification of the material and thus that the data from the last verification are still valid. The continuity of knowledge for the period between these verifications is thus established for the safeguards authority. As long as Requirement 3 is still valid there is no need for permanent safeguards on the flow of nuclear material to maintain the continuity of the safeguards authority's knowledge.

The principle of the safeguards system is based on the examination of the accounting data and independent verification of the material. At no time is a direct independent verification possible in the final repository. As long as the FDP's are still accessible an indirect verification can be effected in accordance with Requirement 2. However, as soon as the FDP's have been emplaced and the tunnel sections backfilled a verification in this form can no longer be implemented either. The outermost covering then consists of the packing material, the surrounding salt rocks and the ends of the tunnel. Verification can now only be implemented indirectly in that the integrity of this covering is verified (Requirement 4).

The problem is how can the integrity of a backfilled or tamped tunnel, and in the post-operational phase the integrity of the whole repository, be rendered verifiable for the safeguards authority. The safeguards system requires that the safeguards authority can make a statement with a quantifiable error tolerance about the quantity of nuclear material present. The safeguards authority can only make this statement by establishing the quantities of material which have been emplaced and subsequently determining the probability with which the quantities of material could be diverted without their knowledge or subjected to an unforeseen application. This means on the one hand that the safeguards authority must monitor the potential diversion paths known to them for material backflows and on the other hand make sure that there are no further undisclosed accesses to the emplaced material, or that the material is not being used for an undeclared purpose.

Requirement 4 implies that safeguarding the potential diversion paths the requirements have basically been fulfilled for the safeguards authority to be able to make the statement necessary for the safeguards system concerning the inventory of enclosed nuclear material. This is basically a question of quantifying the completeness and effectiveness of these measures in the safeguards sense.

### 4.3.2 Material Accountancy

Material accountancy is pure item accountancy. Each FDP is both item and batch. The shipper data from the conditioning facility are taken over unaltered as data on the quantity and composition of material. Since measurements cannot be made in the case of the final disposal packages, these data are not subject to any further alterations. Apart from the possibility of exempting nuclear material from safeguards and apart from material being retransported for rework requirements, the inventory changes to be recorded only consist of additions. The emplacement process is documented by operating records.

The final repository does not display any special features with respect to material accountancy. Only the form and content of the operating records documenting the emplacement process are to be coordinated with the safeguards authority.

### 4.3.3 Containment and Surveillance Measures

#### 4.3.3.1 Seal Devices

The emplacement process is envisaged as a continuous process. As a rule, the incoming FDP's are transported below ground without delay. If a continuous emplacement process is also to be ensured in applying safeguards measures then this requires that the identity and integrity of the FDP's be verifiable in situ without expending much time. This requirement must be considered in designing the outermost shell of the FDP, the lost shielding.

Design criteria for the lost shielding are e.g.:

- homogeneous container with only one opening if possible,
- container made of one material so that it is not possible to open and reseal the containment without leaving visible traces,
- container without a protective coating of paint so that it is possible to directly verify the container walls.

Appropriate devices should be envisaged on the container so that the body and lid can be sealed together. Protective devices against mechanical stress during transport should be envisaged for the seal mechanism.

In any case the seal should be designed in a redundant manner since otherwise in case of doubt about the identity or integrity of the seal it would be necessary to retransport the package to the conditioning facility and open the FDP to reverify the material content. This redundant seal measure should be very robust with respect to all conceivable interferences. For this purpose it would be conceivable to distribute weldment sections along the perimeter across the lid seam of the container. Whereas for the primary seal, the major design criterion is the possibility of verification in situ, this criterion must possibly take second place to robustness in the back-up measure. If back-up sealing requires more time for verification then this must be considered in designing the capacity of the aboveground buffer store.

Two types of seals, paper and metal, are currently in use at the IAEA. The paper seals consist of gummed seal paper and have slits making it more difficult and time-consuming to peel off and reapply the seal without destroying it. They are designed for short-term use. Disadvantages are, however, that they are difficult to handle and are especially easily damaged during transportation of the sealed packages. Application in the final repository is possible for short-term tasks.

Metal seals (type E) consist of two metallic semi-shells which lock together under pressure in such a way that they are practically impossible to open without destroying the seal. A special seal wire is passed through two holes in one semi-shell and knotted inside the shell. By placing the second semi-shell in position the knot becomes inaccessible and the seal is thus closed. This metal seal has the advantage of being easy to handle but it can only be verified in the IAEA laboratory. Verification of the seal is thus generally delayed by several weeks. The metal seal can possibly be used as a back-up seal for the FDP's.

Seal verifiable in situ are not yet part of the standard C/S measures. However, some devices are at an advanced stage of development or testing so that their availability can be expected in a foreseeable period, such as e.g.:

- fiber optic seal
- electronic seal
- weldment seal.

In the case of the fiber-optic seals, the ends of a fiber-optic loop are joined at right angles or crossed over and enclosed by a casing. The arrangement of the individual fibers shows an unambiguous arrangement picture which can be photographed through a microscope and compared with earlier pictures or evaluated by an electronic interrogation unit.

In the case of the electronic seal, a fiber-optic loop is monitored with the aid of statistically generated light pulses and an opening of the fiber-optic loop is recorded at the VACOSS instruments specifying date and time. The seal is interrogated via an adapter box or possibly via a remote interrogation installation. The electronic seals are reusable.

In the case of weldments, there are differentiating features suitable for identity verification both in the melt configuration as well as in the side notch line of the weld. The weld can be verified in two different ways:

- by producing and measuring an impression (microscope),
- photographically.

However, the applicability of weldment seals still has to be practically tested.

4.3.3.2 Optical Sensors

Optical sensors are required to safeguard potential diversion paths for undeclared backflows of material. The following features should be observed:

- Illumination
  An emergency power supply is not envisaged for the underground facilities. An independent emergency power supply must therefore be installed for the safeguards instrumentation.

In order to possibly be able to dispense with emergency illumination it should be considered whether low-light level or infrared cameras can be used.

- Recording Intervals

  In order to be able to recognize a detection with single-frame operation, the image frequency would have to be greater than the minimum time required to pass through the camera's field of vision. Since this would have to be assumed in the range of a few minutes, a relatively high picture frequency would thus be required and a high recording capacity. The problem moreover results with this procedure that if only one, or very few, pictures are available to evaluate a process, then the process can often not be unambiguously interpreted.

Since activities generally only occur sporadically in the visual range of the camera and are of relatively short duration (transport processes), the installation of motion detectors seems to be most appropriate. These motion detectors are electronic cameras which only take pictures if the content of the field of view changes. Since the transportation of an FDP will at any rate cause a large change in the image due to its dimensions, this should probably ensure the triggering of a visual record by FDP transports.

A conceivable alternative would be permanent monitoring with TV cameras and monitors in a safeguards control room. This would however be considerably more expensive since the control room would require a permanent inspector (24 hrs.).

Film cameras do not seem suitable for use in the geological repository since image recording triggered by movement is not possible here. The high image frequency required for single-frame processes would thus involve disproportionally great expenditure for image evaluation.

Two optical safeguards systems are currently employed by the IAEA, twin Minolta cameras and psychotronic TV cameras. The twin Minolta units consist of two identical ciné cameras accommodated in a casing taking single-frame pictures at an adjustable interval. These units are frequently used to safeguard wet storage pools in LWR facilities.

The psychotronic TV cameras are only used in cases of special application since they display great reliability problems. However, a number of advanced TV camera safeguards systems are currently being developed or are at the trial stage so that it can also basically be assumed here that suitable instruments will be available in the foreseeable future.

## 4.4 Diversion Analysis

### 4.4.1. Operational Phase

#### 4.4.1.1 Model 1 (no inspector access to the underground facilities)

The simplest opportunity for a diversion exists on the transport path from the conditioning facility to the final repository. However, it would also be easy to detect due to the measures discussed. If counting, identity and integrity verification are to be regarded as very reliable measures, then a diversion after this verification would have a higher probability of remaining undetected. The safeguards authority's strategy must be to implement these measures at the last possible moment in order to make a clandestine diversion more difficult for the operator. If the inspector has access under ground than he can undertake verification there. Verifications above ground serve to prevent any FDP's whose identity or integrity cannot be established beyond doubt from being transported under ground.at all.

It must be possible to undertake reliable identity and integrity verifications indicating tamper attempts. Otherwise the operator would have the opportunity of replacing the FDP's by dummies during transportation and if this was noticed by the inspector of declaring this as a failure of the seal. Since transportation back to the conditioning facility is necessary for verification, the operator could then replace the dummy by the original FDP during transport and thus conceal his diversion attempt.

Diversion possibilities above ground before transporting the FDP's into the final repository consist in the following activities

- the diversion of FDP's without their replacement
- replacing FDP's by dummies (= FDP without nuclear material)
- clandestine opening of FDP's, removal of nuclear material.

These possibilities of diversion can be detected by:

- counting the FDP's
- identity verification of the FDP's and
- integrity verification of the containers (lost shielding).

These verifications assume that the lost shielding of the canisters is constructed in such a way that any damage to the integrity becomes apparent by inspection. It should be possible to achieve this objective with the envisaged cast container. The container is designed to have two openings each safeguarded by a seal. If the container is opened at any other place then it will have to be welded together which would be detected in an optical inspection of the container walls.

If the requirements of

- tamper-resistant seals verifiable in situ for the lid and bottom openings of the container and
- unambiguous integrity verification of the container walls by an optical inspection (it may also be

necessary to seal the protective neutron covering
of the lost shielding)

for the FDP's could be fulfilled then diversion above ground can be ruled out with great reliability. The FDP's are counted and verified before being transported to the shaft. During these safeguards the

- missing FDP's
- dummies and
- clandestinely opened FDP's

would have to become apparent. The FDP's remain under optical surveillance (human oder camera surveillance) until they are transported under ground.

The diversion possibilities for FDP's transported under ground depend very largely upon the technical expenditure a potential divertor is prepared to invest in order to execute the diversion. Since there is no hot cell facility under ground which would be required to disassemble the FDP's and repack the nuclear material, in the case of a supposed diversion the nuclear material can only be transported above ground in units with at least the dimensions of an FDP. If the hoisting equipment of the shafts were safeguarded by optical instruments the transportation above ground of objects with these dimensions could be detected in any case.

4.4.1.2 Model 2 (Limited Inspector Access to the Underground Facilities)

Whereas in Model 1 the inspector does not have any opportunity of verifying the flow of final disposal packages under ground, strategic points are established in Model 2 in order to safeguard the flow of packages up to the emplacement location. Since underground transport extends for several kilometers continuous monitoring entails a good deal of expenditure. Those points are safeguarded at which the packages are reloaded from one means of transport to another since the possibility of substituting dummies for the FDP's would be most easily achieved here. These points are (cf. Fig. 4-2)

- SP-A strategic point pit bottom at Shaft 2 (not in the Figure)
- SP-B junction of access gallery - emplacement connection drift
- SP-C junction of emplacement connection drift - emplacement tunnel.

A reverification of the FDP's at the emplacement location could be regarded as an alternative or a supplementary measure. This verification can either be undertaken personally, i.e. by the inspector, or by a tamper-resistant recording C/S instrumentation.

The credibility of the safeguards concept can be significantly increased by underground optical safeguards instrumentation. These devices ensure that the existing transport paths cannot be used for a diversion. The cameras at points B are especially significant. They safeguard that the in-coming final disposal packages are actually reloaded onto the emplacement machine and transported to the emplacement connection drift. Furthermore, this camera can also monitor the sealing of the emplacement fields already backfilled. The cameras at points C in the emplacement connection drift ensure that no connection is made from the emplacement connection drift to the exploratory level above it into which the FDP's could then be brought, but rather that they are actually transported into the emplacement tunnels. Surveillance of the emplacement tunnel itself seems to be less meaningful, firstly since at least two emplacement tunnels are always in operation and secondly since a frequent repositioning of the camera would be necessary. Diversion from the emplacement tunnel without retransportation into the emplacement connection drift seems rather implausible since there is no connection from the emplacement tunnels to the exploratory floor.

In this safeguards model it can be credibly demonstrated that the FDP's are actually transported to the emplacement

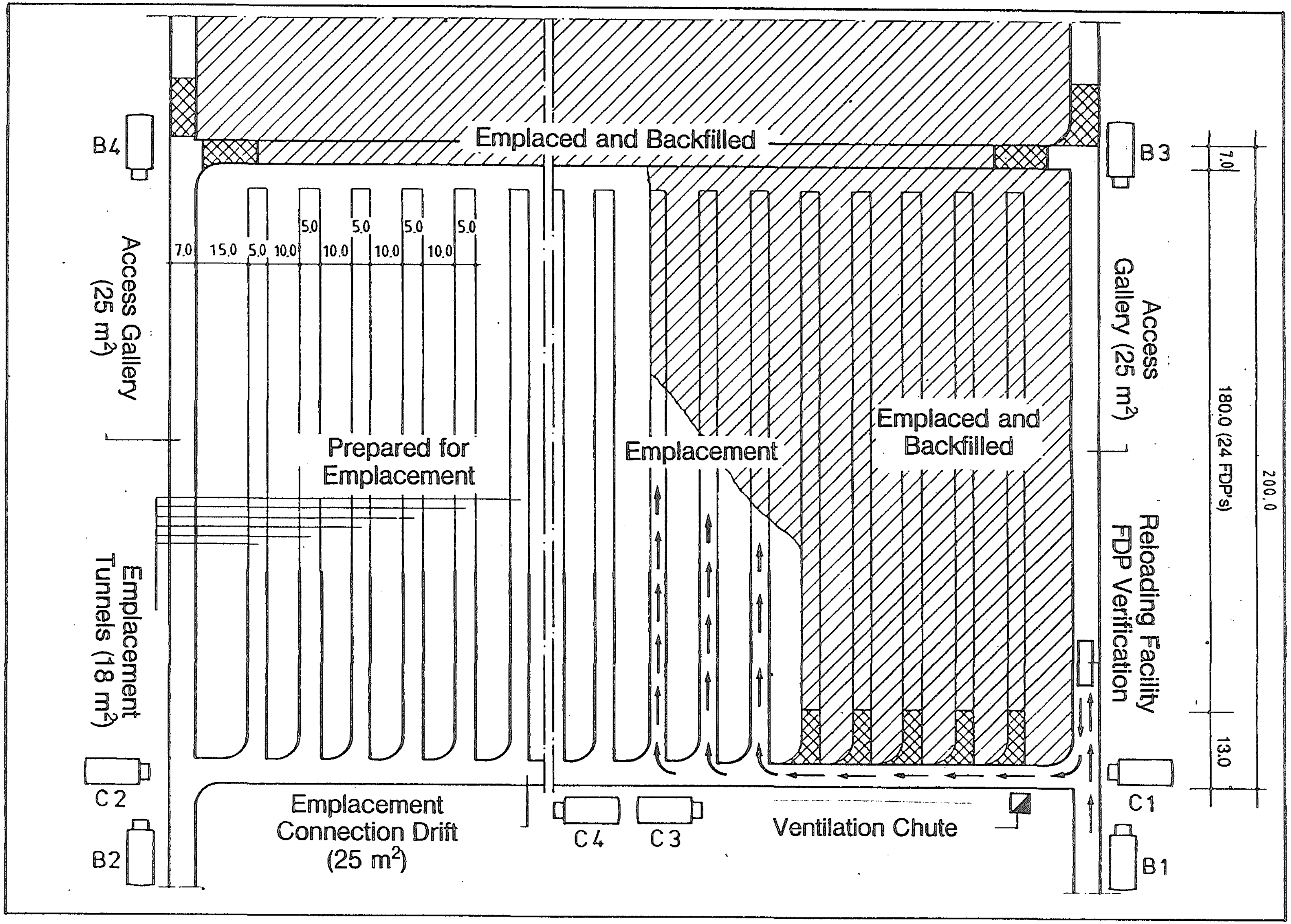



Figure 4-2: Strategic Points in the Emplacement Field

location, the emplacement tunnels are backfilled according to regulations and sealed and that the sealing of the tunnels and fields is not opened again. This requires a relocation of the monitoring cameras, at the latest when emplacement operation is taken up in a new field. This relocation makes it necessary to reverify the instrumentation.

#### 4.4.1.3 Model 3 (Unrestricted Inspector Access to All Underground Facilities)

Even if the inspector is granted limited access to strategic underground points, safeguards opportunities end when the FDP has been emplaced or the tunnel tamped. Opening up the dam again would probably be the easiest, but not the only, possibility for the operator to implement a diversion. It would be possible for him to open up additional access to the material with the equipment available below ground and thus to by-pass the dam sealing the tunnels.

If one does not rule out the possibility of the presence of an underground hot cell facility then the nuclear material from the FDP's could theoretically be repacked into any number of small innocent-looking containers and could be brought above ground e.g. disguised in the debris. The material could perhaps even be processed below ground so that only the strategic material itself without ballast need be brought above ground. The task of checking all transports of material and debris going above ground for concealed nuclear material must in the authors' opinion be regarded as unimplementable. If this diversion opportunity is to be regarded as realistic and thus to be included as a diversion strategy then appropriate safeguards should rather be applied in examining the facility design. A permanent verification of the facility design is from the present perspective the most comprehensive possibility of excluding diversions under ground. However, this requires that the inspectors have access to all underground facilities at all times. Apart from the FDP storage area, this also includes the infrastructure section (workshop, hopper, whole exploratory floor etc.) and the waste package storage area. The inspector must satisfy himself that these facilities are being used in accordance with regulations and not misappropriated for a diversion, and that there are apparently no further undeclared facilities.

### 4.4.2 Post-Operational Phase

The essential aspect of safeguards in the post-operational phase is firstly that the authority satisfies itself that the repository has been sealed according to regulations. This also means that the post-operational phase only begins when both FDP emplacement as well as waste package emplacement has been completed. A diversion in the post-operational phase could be effected by:

1. sinking a purpose-built shaft directly to the enclosed FDP's with the aim of bringing individual or several FDP's above ground, or
2. by clandestinely opening new access to the emplaced material from a considerable distance.

The diversion possibility mentioned in 1 must be classified as at least technically very difficult. Suggested safeguards would be to monitor the site by inspections.

The second possibility of uncovering new access from a considerable distance would be by far the most expensive and time-consuming diversion possibility. It would involve new shafts being driven. The extent to which this could be implemented in practice at all would still have to be examined.

### 4.4.3 Evaluation of Effectiveness

Model 1 proceeds from the following assumptions which are accepted as given facts for the safeguards model and not verified further:

- There are no hot cell facilities below ground.
- There is no other connection from the underground facilities to the surface except via the safeguarded shafts.
- Misappropriation of nuclear material is ruled out within the underground facilities (internal diversion) since EURATOM has access.

In a purely technical consideration, the weakness of this safeguards model is quite clearly to be found in the fact that the complex "clandestine facilities" is by definition not included. It must be remembered that emplacement operation only represents a small fraction of the total handling activities in the final repository. New fields are continually being opened up parallel to emplacement both in the FDP storage area as well as in the waste package area. This necessarily involves extensive debris and material transports. The principle of transparency would not be applicable here either since the underground activities are not transparent for the inspector who can only safeguard at the surface. Design verification before beginning emplacement operation also only provides limited evidence since the extension of the underground facilities is permanently modified.

However, in an overall evaluation of this safeguards model this technical deficit must be seen in relation to other parameters. These other parameters are e.g. quantity, recoverability and strategic value of the emplaced material. The attractiveness of this material for a potential divertor must be compared with the technical and organizational effort required to implement a clandestine diversion. The technical feasibility of a diversion with the aid of clandestine underground facilities can undoubtedly not be basically ruled out. The chances of being able to successfully implement a clandestine diversion in this way must, however, be regarded as extremely remote, especially with respect to the supranational character of national safeguards (EURATOM).

In comparison to Model 1, Model 2 does not provide any improvements in principle, but rather, even if to a considerable extent, only improvements in degree. The existence of clandestine facilities via which a diversion could take place cannot be reliably ruled out in this case either. In this model diversion would be possible by opening up access to the already emplaced FDP's from the workshop area or the waste store.

In Model 3 the inspector is thus practically granted the possibility of design reverification at all times. In this case the danger of detection of undeclared facilities is considerably increased for a potential divertor but nevertheless this possibility is still not reliably ruled out.

The technical feasibility of a diversion has been considered in safeguards models to date. In any case, underground facilities would be required for a diversion in which the FDP's could be disassembled and the nuclear material repacked in unsuspicious packages which could then be brought to the surface disguised in the debris or in items of equipment. The establishment of an underground reprocessing facility would involve considerably more expenditure and an even greater risk of detection. As far as can be foreseen to date there are no technical safeguards which can rule out these diversion possibilities in principle. These diversion possibilities have to be classified as technically feasible, even if requiring immense expenditure.

The diversion scenarios discussed for the post-operational phase would in principle also be applicable in the operational phase. However, they involve greater expenditure and a higher detection risk.

In order to sink a purpose-built borehole, the minimum time would first have to be determined required to sink the borehole, transport the FDP(s) to the surface and cover the traces. These time requirements determine the inspection interval for safeguards.

Site inspections are envisaged as safeguards. Since sinking an appropriate borehole would require extensive technical preparations it is practically certain that these signs would be recognized during a site inspection.

The clandestine sinking of new shafts to recover the emplaced material would probably require even more effort. A further difficulty is encountered in determining the area to be subjected to safeguards. If this diversion possibility is to be considered as realistic so that appropriate safeguards precautions would have to be taken then site inspections would also probably be a suitable measure in this case.

In all models the question of how the effectiveness of containment safeguards in the operational phase or monitoring the site in the post operational phase can be quantified emerges as the principal difficulty. This problem cannot be solved by an exclusively technical approach since in the final repository every safeguards measure can in principle be evaded by increasing the diversion efforts. No safeguards measure can thus be classified as reliable from a technical aspect.

## 4.5 Evaluation of the Effectiveness and Analysis of the Vulnerability of the Safeguards System

### 4.5.1 Phase 1 - Aboveground Transport

This phase begins as the FDP's leave the conditioning plant and terminates when these FDP's are transported via the shaft in the final repository. It therefore comprises the whole time the FDP's spend above ground. Possible diversion strategies during the aboveground transport phase of the FDP's are:

- diversion of the FDP without replacement
- replacing the FDP by a dummy and
- clandestine opening of the FDP and removal of nuclear material.

The envisaged safeguards (see Table: 4-3) for this phase are identical for all three safeguards models. They consist of counting the FDP's, verifying the identity and integrity. The identity is verified on the basis of tamper-proof differentiation features on the outermost cladding of the FDP. This task is taken over by the sealing device with which the body, lid and bottom of the lost shielding are sealed together. So that the seal can be verified immediately before transporting the FDP under ground it must be verifiable on site by inspection or interrogation without time-consuming evaluation processes. This task can for example be fulfilled by an electronic seal.

All FDP's leaving the conditioning plant must pass through this verification procedure within a certain time limit. This ensures the completeness of safeguards in the transport phase at the surface. After verifying the seals, the FDP's are transported into the hoisting cage without further delay. Whether further safeguards against a potential exchange of the FDP's during this period will have to be undertaken depends on the concrete structural features of the surface facilities, these not being currently known. If e.g. it cannot be reliably ruled out that the FDP's could be transported back to the unloading facility without the inspector's knowledge and there replaced by dummies, then this period can be bridged by labelling the FDP's with paper seals.

The envisaged safeguards (identity and integrity verification) should not raise any considerable problems with respect to their reliability and unambiguity since they can both be repeated as often as required. Only the seal could possibly be damaged during transport procedures. Diversified redundancy is envisaged as a supplementary procedure, i.e. for example a robust mechanical seal in parallel to an electronic seal. If in exceptional cases it is no longer possible to clearly identify the FDP's, e.g. due to transport damage to the seal, then at this phase the possibility still remains of bringing these FDP's back to the conditioning plant and measuring them again. Retransport after transportation accidents would probably be necessary in any case.

If the completeness of the safeguards can be taken as given then the following parameters remain which could impair effectiveness, namely tamper-resistance and the possibility of outwitting the safeguards. These parameters can, however, be influenced by the design of the outermost cladding of the FDP's and by the choice of seal(s). No significant difficulties are envisaged on the basis of the current state of the art. Sufficient safeguards can thus be ensured, in the author's opinion, during the phase of transporting the FDP's above ground.

4.5.2 Phase 2 - Transport Under Ground

This phase begins with the transportation of the FDP's through the shaft and finishes when the tunnel section already occupied by FDP's are filled in. It thus comprises the whole period when the FDP is accessible for direct monitoring or verification of the identity or integrity of its cladding under ground.

Two steps are required to divert nuclear material during this phase. First of all, the FDP's would have to be withdrawn from the normal operational sequence, i.e. smuggled out of the emplacement process and thus out of the reach of further safeguards. This can in principle be achieved with the same diversion strategies as during the aboveground transportation phase (see Table 4-4).

The second step consists of subjecting the clandestinely removed FDP's to an undeclared application (see Table 4-5). This means that the FDP's must be further processed in a suitable facility. The decisive criterion for safeguards is whether the operator clandestinely modifies the plant design so that the FDP's can be transported to the further processing facility without being noticed or whether he undertakes this diversion via the existing transport paths. In the case of a diversion without modifying the plant design, the FDP's will have to be retransported via Shaft 1 or Shaft 2.

If one assumes that it is also possible to modify the facility design in order to implement a diversion then three alternatives would theoretically result:

1. The establishment of a clandestine hot cell facility under ground to disassemble the FDP's and repack the nuclear material into small, innocent-looking containers which can then be brought to the surface unnoticed in the material or debris transports.

2. Construction of a clandestine underground facility to separate the strategic material from the FDP's.

3. Creation of an additional clandestine connection to the surface via which whole FDP's or repacked smaller quantities of material can be transported unnoticed.

4.5.2.1 Model 1

In Safeguards Model 1 it is assumed that clandestine design modifications can be ruled out. Since in this model the inspector has no underground access, no safeguards can be applied underground either. The operator could thus implement the first step in a diversion, i.e. clandestinely removing the FDP's from the normal emplacement process, without being noticed. However, in order to complete the diversion the FDP's would have to be retransported to the surface via either Shaft 1 or 2. Diversion strategies and safeguards are compiled in Tables 4-4 and 4-5. Optical monitoring of the transport facilities is envisaged as a safeguard against retransport. Unloading objects from the transport facilities with at least the dimensions of an FDP would be the anomaly to be observed indicating a diversion. However, for Shaft 2 it must be ensured that

- the retransportation of objects of these dimensions actually means an anomaly, i.e. does not occur in the normal operating sequence and
- this event can be optically unambiguously identified.

Apart from the dimensions, the weight of the object can also indicate an anomaly since in normal operation no retransportation is to be expected in the range of more than 25 t (based on the removal of debris or other normal operational transports to the surface). However, the direction and load of the hoisting equipment must be recorded in a tamper-proof manner which could be achieved via the consumption of electricity of the winding engine.

This measure is not required for Shaft 1 since an FDP does not geometrically fit into the hoisting cage. Neither is there any device at Shaft 1 to balance the elongation of the rope of several meters /4-4/ which would occur if an FDP were attached to the hoisting cage. It can be assumed that this type of extensive action would be reliably optically detected by the safeguards devices.

In order to be able to make concrete statements about the reliability and possibilities of outwitting the safeguards, concrete data about the structural form of the transport facilities and buildings are necessary in order to then be able to determine e.g. where the camera should be installed, the possibility of unintentionally impairing or blocking the field of vision, possibilities of deception by dazzling or turning off the illumination etc.

However, in the authors' opinion this safeguards task should be categorized as capable of being satisfactorily solved. Roughly comparable tasks such as fuel element handling in LWR wet storage pools have already been satisfactorily solved for years in common practice by optical safeguarding. Providing that there is no need to consider an undeclared modification to the facility design, effective safeguarding should be realizable with Model 1 in this phase. If this presumption cannot be made then Model 1 does not provide complete safeguarding of all diversion possibilities and thus would be unacceptable to the safeguards authorities.

4.5.2.2 Model 2

In Model 2 the inspector has access to strategic points below ground and is thus also in a position to monitor the nuclear material flow under ground. Over and above Model 1, Model 2 attempts to detect the first step in a diversion, namely the clandestine removal of FDP's from the normal operational sequence.

In the first place, optical monitoring of the reloading process is envisaged at all points where the continuous transport is interrupted due to reloading to a different means of transport, since at these points it would be easiest to divert the FDP without replacement or to substitute a dummy. The first of these points (strategic point A) is when unloading the plateau transporter from the hoisting cage at the filling station of Shaft 2. Safeguards will ensure that the FDP transported under ground is also actually unloaded into the emplacement floor. The second safeguards point (strategic point B) is the reloading facility from the access gallery to the emplacement connection drift. This camera observes the reloading of the FDP's from the plateau transporter to the emplacement machine. Further safeguards devices are envisaged in the emplacement connection drift itself (strategic point C). It can thus be observed whether the FDP's are transported to the envisaged emplacement gallery by the emplacement machine and also remain there. See Fig. 4-2 for the position of strategic points B and C.

Due to the long underground transportation paths (several kilometers), uninterrupted transport monitoring would be unjustifiably expensive. Since transportation only occurs sporadically and the FDP's can only be within the visual range of the individual cameras for a very short period, these safeguards devices should be equipped with motion detectors. All movements within the visual range of the camera can thus be completely recorded without having to envisage unnecessary frame storage capacity, and thus also frame verification expenditure, for the periods with no movement. If the date and time of the event are recorded with the movement then delays in transportation which would be required to manipulate the FDP's or replace them in the zones not directly safeguarded could be detected. This thus provides a high degree of reliability to ensure that the FDP's transported below ground are brought into the envisaged emplacement tunnels without manipulation.

As a supplementary or alternative measure a reverification of the FDP's deposited in the emplacement tunnel can be undertaken by the inspector. The cameras at the strategic points B and C furthermore ensure that the FDP's deposited in the emplacement tunnel are not subsequently removed again. This process would be recorded by the cameras. A technical problem still to be studied in detail is the tamper-proof transmission of the frames to a safeguards control room which could most appropriately be situated above ground.

Over and above the possibilities of Model 1, Model 2 can thus ensure that the envisaged operational sequence is observed and no FDP's are clandestinely removed. The primary measure is optical safeguards at the strategic points A, B and C. FDP's deposited in the emplacement tunnel can be reverified by the inspector as a substitute measure in case of camera failure and on a random basis to reduce the residual risk of manipulating FDP's in the unsafeguarded intermediate areas. This should not cause delays in the operational sequence since there is usually a shift loss by breaks between emplacement and backfilling. In this phase Model 2 should thus provide sufficient reliability that the first step in a diversion, clandestinely removing FDP's from the normal operating sequence, can be detected.

With respect to the second step necessary for a successful diversion, namely clandestine transportation of the FDP's to the further processing facilities, Model 2 is identical to Model 1 (see also Tables 4-4 and 4-5). This safeguard thus represents an additional barrier for a potential divertor.

#### 4.5.2.3 Model 3

Model 3 goes beyond Model 2 by envisaging a further barrier for the second step required in a diversion, transporting the FDP to the further processing facilities after clandestine removal. This barrier consists in the right granted to the inspectors of reverifying the plant design at all times. This measure is admittedly primarily aimed at the next phase but it already functions as an additional safeguard in Phase 2. It must be noted that the safeguards measures for Step 1 and Step 2 are not to be regarded alternatively but rather cumulatively (see Tables 4-4 and 4-5). In addition to the safeguards outlined in Step 1, the safeguards in Step 2 must also be overcome for a successful diversion.

### 4.5.3 Phase 3 - Storage During the Operational Period of the Final Repository

This phase comprises the period after packing the individual tunnel sections occupied by FDP's until backfilling of the final repository shafts, that is to say the period in which mining activities are being implemented in the vicinity of the emplaced FDP's.

Two steps are also required at this stage for a successful diversion. Since the FDP's are already stowed at this phase, the first step consists of making the FDP's accessible by uncovering an entrance. The second step is identical to the second step of the previous phase. Strategies and measures for this phase are shown for all three safeguards models in Tables 4-6 and 4-7. The uncovered FDP's must be transported to the processing facilities. However, in contrast to the second phase, here in the third phase the first diversion step is already possible by an undeclared design modification. The uncovering of an entrance to the already backfilled or tamped emplacement tunnels is either possible directly by reversing the emplacement process, i.e. opening up these tunnels starting from the available galleries, or indirectly by creating new clandestine entrances from non-safeguarded areas, e.g. hopper, workshop, exploratory level or even the waste storage area.

4.5.3.1 Model 1

No new safeguards are envisaged in Model 1 for this phase. The same assumptions are valid as for the previous phase, i.e. that undeclared alterations to the facility design are ruled out. A diversion would be detected when retransporting the FDP via the shaft facilities.

4.5.3.2 Model 2

Model 2 already begins at the first step in a diversion, uncovering access to the FDP's. The range of effectiveness of the safeguards envisaged for Phase 2 is thus extended. The integrity of the tunnel closures and material recovery via this path can be monitored by the safeguards devices installed at the strategic points. Human verification of the tunnel closures by inspection is envisaged as a substitute measure in the case of camera failure and as supportive measure on a random basis.

The diversion strategy for the first step required in a diversion can be detected by these safeguards. The uncovering of a clandestine access by by-passing the sealing devices cannot be detected by the safeguards envisaged in Model 2. Further safeguards are therefore discussed in Model 3 as a protection against this diversion strategy.

4.5.3.3 Model 3

Model 3 envisages permanent design reverification on a random basis for all underground facilities. In order to conceal the uncovering of the FDP's a potential divertor will make this attempt from areas to which the inspector has no access. The most effective method of preventing this diversion strategy is thus to grant the inspectors unrestricted access to all facilities of the final geological repository. The inspectors must be able to satisfy themselves that there are no undeclared connections or facilities within the geological repository and that only emplacement activities are being implemented.

Permanent design reverification is a safeguard which applies to both the first and the second diversion step. In the authors' opinion it thus represents the most comprehensive safeguard against undeclared activities, nevertheless its effectiveness is difficult to quantify.

### 4.5.4 Phase 4 - Post-Operational Phase of the Final Repository

This phase begins with the closure of the geological repository by backfilling the shafts and lasts as long as the material is subject to safeguards.

In this phase diversions can be implemented by:

- sinking a purpose-built borehole or shaft to recover one or a few FDP's or
- reopening the repository, e.g. from a considerable distance, to divert larger quantities.

Periodic inspections of the site to verify the integrity of the sealed geological repository are envisaged as safeguards.

Drilling or sinking activities at the repository site could certainly be detected during the site inspections. The inspection intervals would therefore only have to be shorter than the necessary diversion period, i.e. the time required to sink the borehole or shaft, recover the FDP's and cover the traces. Whether reopening of the repository can be detected by site inspections depends on the distance from which it is reopened. Even if the effectiveness of this safeguard is difficult to quantify, site surveillance represents in the authors' opinion the most suitable safeguard for verifying the integrity of the shutdown repository.

## Phase 1: Transport Above Ground

### Conditioning Facility Exit – Beginning of Shaft Transportation

| Diversion Strategy | Safeguards Measures<br>Model 1 Model 2 Model 3 |
|---|---|
| Diversion of Whole FDP's | Counting the FDP's |
| Replacement by Dummy FDP | Seal Verification and FDP Integrity Verification Upon Entering the MBA, Subsequent Optical Monitoring |
| Removal of NM from the FDP | FDP Integrity Verification Upon Entering the MBA, Subsequent Optical Monitoring |

Effectiveness: Acceptable

Table 4-3: Safeguards in Phase 1 – Transport Above Ground

## Phase 2: Transport Under Ground

### Beginning Shaft Transportation – Backfilling on Site

| Diversion Strategy | Safeguards Measures<br>Model 1 | <br>Model 2 | <br>Model 3 |
|---|---|---|---|
| **1st Step:**<br>Clandestine Removal of FDP or NM from the Operational Sequence | | | |
| a) Diversion of Whole FDP's | — | Counting the FDP's | |
| b) Replacement of FDP by Dummy<br>c) Removal of NM from FDP | — | Transport Monitoring with TV Camera at SP A, B and C<br>*and/or*<br>Random Seal Verification and FDP Integrity Verification before Emplacement<br>*and*<br>Monitoring Potential Diversion Paths with TV Camera at SP's B and C | |

Table 4-4: Safeguards in Phase 2 – 1st Diversion Step

## Phase 2: Transport Under Ground

### Beginning of Shaft Transportation – Backfilling on Site

| Diversion Strategy | Safeguards Measures<br>Model 1 | <br>Model 2 | <br>Model 3 |
|---|---|---|---|
| **2nd Step:**<br>a) Retransportation of FDP's to the Surface Disguised as Debris or Material | TV Camera at Both Shafts, Tachograph and Load Recorder at the Winding Engine of Shaft 2 (25 t-Criterion) | | |
| b) Underground HC Facility Repacking the NM in Unsuspicious Containers, Retransportation through Existing Facility<br>c) Underground RP Facility<br>d) Clandestine Connection to the Surface | —— | —— | Permanent Design Reverification of all Underground Facilities, Verification for Undeclared Design and Activity Alterations |

Effectiveness: Acceptable since FDP's Still Accessible

Table 4-5: Safeguards in Phase 2 – 2nd Diversion Step

## Phase 3: Storage During the Operational Period
## Backfilling the FDP's – Closing the Geological Repository
## (Backfilling the Shafts)

| Diversion Strategy | Safeguards Measures: Model 1 | Safeguards Measures: Model 2 | Safeguards Measures: Model 3 |
|---|---|---|---|
| **1st Step:** Access to Emplaced FDP's | | | |
| a) Uncovering and Diverting FDP's via Existing Transport Paths | — | TV Cameras at SP B (Tunnel Closure) and SP C (Emplacement Connection Drift)<br>Random Verification of Tunnel Closures by Inspectors | |
| b) Clandestine Entrance by By-Passing Tunnel Sealing via Exploratory Floor, Waste Store etc. | — | — | Permanent Design Reverification of All Underground Facilities |

Table 4-6: Safeguards in Phase 3 – 1st Diversion Step

## Phase 3: Storage During the Operational Period
## Pneumatically Packing the FDP's – Closing the Geological Repository (Backfilling the Shafts)

| Diversion Strategy | Safeguards Measures Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| **2nd Step:** | | | |
| a) Retransportation of FDP's to the Surface Disguised as Debris or Material | TV Camera at Both Shafts, Tachograph and Load Recorder at the Winding Engine of Shaft 2 | | |
| b) Underground HC Facility Repacking the NM into Unsuspicious Containers, Retransportation through Existing Shaft Facility<br>c) Underground RP Facility<br>d) Clandestine Connection to the Surface | ——— | ——— | Permanent Design Reverification of all Underground Facilities<br><br>Verification for Undeclared Design Modifications and Changes in Facility Operation |

Effectiveness: Unsolved Problems

Table 4-7: Safeguards in Phase 3 – 2nd Diversion Step

## Phase 4: Post-Operational Phase after Backfilling the Shafts

| Diversion Strategy | Safeguards Measures | | |
|---|---|---|---|
| | Model 1 | Model 2 | Model 3 |
| Purpose-Built Borehole or Sinking a Shaft to Recover Individual FDP's<br>Reopening the Repository from a Considerable Distance to Recover a Number of FDP's | Optical Surveillance of the Site by Periodic Inspections | | |

Effectiveness: Open Problems

Table 4-8: Safeguards During the Post-Operational Phase of the Final Repository

## 4.6 Resulting Problem Definition

The basic problem to be quantified in applying C/S measures is the probability with which a diversion can be detected by these safeguards. In contrast to material accountancy, there is not yet any fully developed method in applying C/S safeguards for determining MUF values (Material Unaccounted For). In practice this problem is avoided by ensuring that materials safeguarded by C/S measures are also in principle directly accessible by measurements and the safeguards authorities reserve this option. Since this option is no longer available for the final repository, quantification of the effectiveness of C/S safeguards takes on particular significance.

The weak point which has been identified in safeguarding the final repository is the limited possibility of safeguarding the integrity of a backfilled and sealed tunnel against tamper attempts through clandestinely driven undeclared entrances. Containment safeguards satisfying the demands of completeness cannot be implemented for a tunnel. The emplaced material can therefore not be sufficiently safeguarded in the mathematical sense. No measures are currently known or envisaged which could ensure sufficient safeguarding. We are indeed convinced that with permanent design reverification a diversion by means of clandestine, undeclared entrances or facilities is practically impossible to implement, nevertheless this cannot be ruled out in the sense of a mathematically logical proof nor can its detection probability be determined. Precisely this is an indispensable requirement for the safeguards system.

The major problem with respect to the safeguards concept for the final repository is that as soon as the material is emplaced safeguards can only be reinforced by C/S measures. The option of direct verification is no longer technically possible. Furthermore, the envisaged C/S measures cannot be objectively quantified with respect to their completeness and thus their effectiveness. Thus the requirements for an applicable safeguards concept required by the safeguards authorities cannot be fulfilled, judged by current practice.

# 5 SOLUTIONAL APPROACHES

## 5.1 Modifications to the Existing IAEA Safeguards Philosophy

### 5.1.1 Relativizing Numerical Detection Goals

The objective of the safeguards to be applied by the IAEA within the framework of the Verification Agreement is defined in Art. 28 VA:

> "The objective of the safeguards procedures set forth in this Agreement is the timely detection of the diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown and deterrence of such diversion by the risk of early detection."

In order to create a planning and evaluation basis for applying safeguards and in order to be able to make the declaration required in Article 30 VA on the technical conclusion of verifications, the IAEA considers it necessary to quantify these objectives. This is achieved by setting up numerical detection goals. These are:

- significant quantity
- detection time
- probability of detection and
- probability of false alarms.

The values currently set up for these detection goals have admittedly only been provisionally accepted, however they can de facto only be questioned if they can be replaced by better alternatives from the IAEA's point of view.

The definition of quantitative goals, even if they are not to be mechanically applied but rather only as guidelines, leads inevitably to the measures envisaged in a safeguards concept having to be quantifiable with respect to the degree of achieving their objective or, (more or less subjectively) quantified. In this technically quantitative approach the planning and evaluation of safeguards is implemented under the aspect of the numerical contribution they could make to the definitions of the goals.

The IAEA is admittedly aware that the quantified detection goals cannot be applied as rigid definitions and thus derives inspection goals from the detection goals where technical feasibility and facility-specific features are included in their determination, nevertheless the principle of a quantified safeguards model as such is not questioned. The measurable variable of detection probability is the central parameter for the IAEA to which safeguards planning, application of funds and evaluation of effectiveness are oriented.

Since there is currently no procedure by means of which the detection probability in applying C/S measures can be quantified safeguards models which are largely or, as in the final repository, almost exclusively based on C/S measures cannot be objectively planned by this approach nor their effectiveness calculated. This leads to them being classified by the IAEA as unacceptable. This fact has also been identified as the basic problem for the safeguards concept of the final repository.

This can be regarded as the starting point for a fundamental criticism. The basically plausible procedure of creating an objectifiable planning basis by numerical definition of goals cannot be rigorously realized in practice. As long as on the one hand C/S measures play, and indeed must play, an important role in safeguards practice, but on the other hand are not quantifiable or only by subjective evaluation, this will lead to a distortion of the planning data which then casts doubt upon the aim of an objectifiable planning basis. The task would consist of upgrading the IAEA's safeguards philosophy by developing alternative planning and evaluation processes in such a way that attributes of effectiveness and credibility could also be applied to safeguards concepts without objectively quantifiable detection probability. That this can be implemented, at least for individual cases, on the basis of a consensus is a prerequisite for the applicability of the suggested Safeguards Model 3. A consensus would have to be achieved with the IAEA concerning the evaluation of the envisaged possibility of permanent design reverification which apparently represents a considerable obstacle to diversion but whose effectiveness can in the last analysis not be verified.

### 5.1.2 Safeguarding of the Fissionable Material FLow

In signing the NP Treaty on November 28, 1969 the Government of the Federal Republic of Germany declared that it

- assumed that the agreements described in Article III of the NP Treaty between the IAEA and the European Atomic Energy Community were concluded on the basis of the verification principle and that verification would be implemented in such a manner that the political, scientific, economic and technical tasks of EURATOM would not be impaired (Item 13 of the Declaration),

- insisted that the safeguards only be applied to source and special fissionable material and in accordance with the principle of an effective safeguarding of the flow of fissionable material at certain strategic points (Item 14 of the Declaration).

It further declared that it only intended to ratify the NP Treaty if an agreement corresponding to Article III of the NP Treaty between EURATOM and IAEA were concluded fulfilling in form and content the requirements of the above mentioned Items in its Declaration (Item 17 of the Declaration).

These principles drawn up jointly with other EURATOM states are laid down in the Verification Agreement and have determined the position of the Federal Government to date.

Among the considerations for the Verification Agreement it is mentioned that

> "the Agency . . . has the responsibility to assure the international community that effective safeguards are being applied under the Treaty".

In Articles 1 and 3 of the VA

- the States of the Community undertake, in accordance with the terms of this Agreement, to accept safeguards on all source or special fissionable material for the purpose of verifying that no diversion has taken place (Article 1) and

- the Community undertakes to co-operate with the Agency, in accordance with the terms of this Agreement, with a view to ascertaining that such source and special fissionable material is not diverted to nuclear weapons or other nuclear explosive devices.

In a strict interpretation of the Verification Agreement it could be argued that since safeguards only refer to the material and not to the facilities that the consideration of diversion scenarios requiring a clandestine alteration to the plant design, such as internal diversion or diversion via clandestine accesses, need not be taken into consideration. Sufficient safeguards could thus be ensured by Models 1 or 2.

As long as there is at least in principle the possibility of satisfying oneself positively of the presence of the material by direct monitoring, the argument of safeguarding the flow of fissionable material at strategic points can be put forward. Since this flow monitoring is no longer possible in the final repository - the FDP's and thus the fissionable material being no longer accessible after backfilling - there is no longer any basis for arguing that safeguards should be restricted to the material itself and diversion scenarios requiring clandestine alterations to the facility need not be considered.

However, effective safeguards on the basis of monitoring the flow of fissionable material at the strategic points can no longer be technically implemented in the final repository so that additional agreements could be made in order to grant the IAEA an equally effective safeguards possibility. However, this type of agreement, which would undoubtedly be compatible with the spirit of the Verification Agreement, would involve legal questions which would be difficult to solve.

### 5.1.3 Releasing Fissionable Material from Safeguards

The basis for terminating safeguards is laid down in Article 11 of the VA: "Safeguards under this Agreement shall terminate upon determination by the Community and the Agency that the material has been consumed, or has been diluted in such a way that it is no longer usable for any nuclear activity relevant from the point of view of safeguards, or has become practically irrecoverable."

These criteria are not fulfilled by the FDP's. The nuclear material in the FDP's is neither diluted nor consumed in such a manner that it is no longer usable for any nuclear activity. The only approach would be the argument that due to the type of emplacement the FDP's are practically irrecoverable. If at all, this argumentation can only be applied to the post-operational phase of the repository, i.e. when all tunnels and shafts have been backfilled and the transport facilities decommissioned. During the operational phase of the repository the emplaced material cannot be classified as irrecoverable since all the equipment necessary to recover the already emplaced FDP's from below ground is available there.

Even if the irrecoverability of the FDP's could be assumed for the post-operational phase this would not improve the safeguardability of the repository during the operational phase, although due to the rise in rock temperature a diversion already becomes more difficult in the operational phase.

Even in the post-operational phase recoverability cannot be classified as technically impossible in principle. Recoverability must rather be regarded as a question of the technical expenditure to be employed. In view of the attractiveness of the emplaced material it cannot be assumed that the safeguards authority would be prepared to classify the material as irrecoverable in the post-operational phase and thus release it from safeguards.

The criteria of Article 35 of the VA are rather to be applied. . . . Where the conditions set forth in Article 11 are not met, but the Community considers that the recovery of nuclear material subject to safeguards under this Agreement from residues is not for the time being practicable or desirable, the Agency and the Community shall consult on the appropriate safeguards measures to be applied.

A statement on what the IAEA regards as appropriate safeguards cannot be currently made.

By way of summary it can be said that in all probability a final release of the material from safeguards will not be possible for the post-operational phase either. The Agreement envisages a mutual agreement on suitable measures for this case. The attitude of the safeguards authorities to these measures still has to be sounded.

### 5.1.4 Considerations of Deterrence

The aim of safeguards is laid down in Article 28 of the VA:

> "The objective . . . is the timely detection of diversion of significant quantities of nuclear material . . . and deterrence of such diversion by the risk of early detection."

The degree of deterrence is the result of weighing the consequences of detection against the advantages of a diversion. The concept of risk can be defined as the product of the probability of an event occurring and the consequences of this event. Of these two variables only the probability of occurrence ( = probability of detecting a diversion) is considered by the IAEA due to their purely technical approach in which the probability of detecting a diversion is the central value.

The second component of the risk concept, the consequences of a detected diversion, contains a large number of variables which cannot or only with difficulty, be quantified. No approaches are currently available which would make such a quantification possible. A starting point here would be granting a safeguards credit corresponding to a state's degree of vulnerability to sanctions. In the case of the Federal Republic of Germany for example, as a country poor in natural resources and strongly export-oriented, the vulnerability to sanctions and thus the extent of the consequences of detection would be very great. Taking these factors into consideration, even with a low technical probability of detection a high detection risk would result for the Federal Republic of Germany. However, it is extremely unlikely that the IAEA will accept this modification in attitude in the short term.

## 5.2 Further and Possibly Re-Development of Safeguards Elements

During the operational phase the problem consists of providing a quantifiable certainty by suitable measures on the part of the safeguards authority that the emplaced material is still present. This quantification is, strictly speaking, only possible for accountancy measures. No methods have yet been developed for numerically determining the effectiveness of C/S measures. The errors involved in C/S verification cannot be precisely specified. This problem can generally be ameliorated in other facilities in that material verification is basically implemented by accountancy measures and C/S measures are only employed for sub-quantities of material and for limited periods as back-up measures. These restrictions (limitation to sub-quantities and limited periods) cannot apply to the final repository. Safeguards would only be possible with purely a C/S concept and, as already mentioned, there is no contractual or methodological basis for this.

This means, even presuming that safeguards elements could be redeveloped or further refined and thus C/S-supported monitoring of the emplaced material were possible, it could only be included in the safeguards system as a supplementary measure. This alone does not represent a basic solution to the problem in hand. Even assuming that new safeguards elements were successfully developed, considerable efforts would still be required to further develop the theory on which the safeguards system is based in order to incorporate these new elements in the safeguards system as essential measures. The development of new safeguards elements would thus only be the first step in solving the safeguards problem.

The backfitting problem must also be seen in this context. As long as there is a possibility of measuring the material in the fuel cycle again at successive intervals, the safeguards system can tolerate the application of C/S measures whose effectiveness is not precisely quantifiable since this uncertainty can at least be eliminated in retrospect in a measuring process. If there is no longer any possibility of subsequently eliminating C/S uncertainty by a measuring process then in order to maintain the effectiveness of the safeguards system very strict standards must be applied to the tolerable error range of C/S measures.

This can be illustrated by an example. In the intermediate storage of fuel elements to be reprocessed at a later stage, a diversion from the storage phase will be detected at the latest in measuring the material at the reprocessing plant. The effectiveness of the C/S measures during the storage period can thus at least be verified in retrospect. The longer the period to be bridged by C/S measures between two measurements in the material cycle, the higher are the requirements which must be made on the effectiveness of these C/S measures. If there is no longer any possibility of a final measurement then the C/S measures applied must provide the same reliability as a measuring process in order to be able to achieve the safeguards objective.

Only a relatively inadequate measurement of spent FE's is possible without chemical dissolution. If there is no reprocessing involving this measuring possibility then it could be argued that the whole FE repository should be more extensively and rigorously safeguarded. In addition to the problems already mentioned, others still have to be solved e.g. the tamperproofness of the individual components in the C/S system.

### 5.2.1 Application and Range of Effectiveness of Surveillance Measures (Inspector Presence and Optical Surveillance)

Optical monitoring is employed as a material flow indicator above and below ground: above ground at the hoisting facilities of the shafts in order to be able to detect the retransportation of FDP's via these facilities, and below ground in order to monitor the emplacement process and safeguard the tunnels against recovery of the material. For a number of years the IAEA has already been gathering experience in employing TV cameras for safeguards purposes. The problems arising here mainly concern the quality of the pictures and the reliability of the instruments. TV cameras have an advantage over film cameras due to their greater flexibility with respect to adapting to different conditions of application, in this case application as a low light-level or infrared camera and the possibility of being connected to other equipment such as the motion detector and also fading-in date and time. The problem of reliability is not so decisive for the final repository since a permanent inspector presence at the repository is required anyway. By means of automatic operational status monitoring it is possible to detect instrument defects within minutes or hours. These failures would have to be regarded as uncritical with respect to the safeguards objective due to the redundant safeguards design.

Due to the large number of optical safeguards instrumentations envisaged it seems meaningful to install a safeguards control room in the final repository from which the operational status of safeguards instruments can be permanently monitored and which also houses a central facility for storing and visually verifying the recorded frames. Due to the dimensions of the facility distances of several kilometers must be bridged between the monitoring instruments on site and the control room. Extensions and new developments are necessary to bridge these distances and to combine the individual instruments in one control room. The safeguards system envisaged for application in Candu reactors can be regarded as a comparable development, even if on a considerably smaller scale. This system is still currently at the development and trial stage and should be able to contribute valuable experience for designing camera safeguards in the final repository.

### 5.2.2 Application of Novel Safeguards Techniques

A number of possibilities for detecting diversion attempts can be conceived. In this context the application of microseismic instruments as sealing and containment surveillance devices for tunnels or fields already backfilled would have to be examined in detail. These instruments would have the task of indicating the application of mining equipment or drilling operations in tunnels and fields already backfilled. A further difficulty here is undoubtedly that tunnels are being backfilled and new tunnels simultaneously driven in relative proximity to each other so that considerable demands must be made on the spatial locating ability of the seismic instruments in order to be able to differentiate normal operational processes from potential diversion activities. It could possibly be of advantage here that emplacement is only envisaged in retreating working and thus the direction of a located source of vibration could be used as a differentiating feature for permissible and impermissible activities.

At any rate, the effectiveness of such detector messages would have to be investigated in detail since microseismic instruments have not yet been employed for safeguards purposes and thus no experience of any kind is available. Particular attention would have to be paid to the false alarm rates to be expected and the necessary subsequent operations, as well as possibilities of tampering and deception to conceal a diversion attempt. Since in conventional applications very much less importance generally has to be attached to these aspects considerable efforts will still have to be applied to determine these variables.

### 5.2.3 Application of Facility Safeguards

The possibility of permanent design reverification has already been envisaged as an additional measure for Safeguards Model 3. However, this measure has a similar effect to extensive facility safeguards and thus raises a large number of basic problems. The declared objective of the Federal Republic of Germany and the other EURATOM states has so far been to restrict IAEA safeguards to the material itself and to only grant the IAEA inspectors access to the predetermined strategic points. Conceding permanent design reverification represents a considerable deviation from this basic principle and should be examined in detail due to its possible trend-setting effect. In addition to the associated surrender of sovereign rights, this measure would also represent a considerable burden for the operator since the inspector would have to be accompanied by operating personnel during his inspections. It can admittedly be assumed that no commercial or industrial processes or equipment requiring protection are used in the final repository which would necessitate strict access controls, nevertheless restrictions on the inspector's freedom of movement with respect to time and place could be necessary to maintain an unimpeded operational sequence.

Extensive site surveillance could be considered in a similar or even more intensified manner as a further safeguard against the uncovering of an additional clandestine entrance. Extensive mining activities would undoubtedly be detected by monitoring a delimited area, e.g. by helicopter, for the purpose of visual site surveillance or aerial photographs. However, it must be considered whether the required losses of sovereignty are still acceptable.

As in all indirect safeguards, the essential aspect in this case is that the detection of an anomaly cannot be equated with a diversion. If these safeguards indicate an anomaly then this can only be used as a reason for closer examination. The contribution made by indirect safeguards within the framework of a safeguards concept terminates when in examining an indicated anomaly no satisfactory explanation can be found for it. At this point at the latest, safeguards must then be employed which make it possible to provide information about the presence of the material with quantifiable reliability.

## 5.3 Adaptation of the Reference Concept to Valid Safeguards Practice

With respect to the safeguards system the problematic aspects of the reference concept consist of the fact that

- the material must continue to be safeguarded even after emplacement and
- due to the inaccessibility of the material, the demands made in valid safeguards practice cannot be fulfilled with respect to verification possibilities.

Starting points for adapting the reference concept thus result by:

1. conditioning or storing the material in such a way that the criteria for terminating safeguards are fulfilled or
2. storing the material in such a way that it remains accessible for verification measures.

Conditioning the material in such a form that the criteria for termination could be regarded as fulfilled would require that the fuel be converted into a glass or ceramic product. This possibility has been considered in more detail by dissolving, diluting and compacting spent nuclear fuel. This was based on the conditioning of fuel in the form of PAMELA moulds. The essential data for this method of treatment resulted in approx. 465,000 PAMELA moulds per year of vitrified nuclear fuel at an annual throughput of approx. 700 tons. In order to emplace these moulds, approx. 6 - 8 shafts per geological repository would be required; a salt dome of the size of Gorleben would be able to accommodate a maximum of 425,000 moulds under the most favourable conditions /5-1/. This method can thus be ruled out as a realistic alternative.

In our opinion there is no possibility of unequivocally fulfilling termination criteria by the type of emplacement in the case of final disposal packages with undiluted nuclear material. Even in the case of borehole emplacement without lost shielding, envisaged as a back-up solution, recoverability of the material cannot be ruled out. All considerations of recoverability take the current state of mining engineering as a variable. Final release of the material from safeguards would require that the material should remain irrecoverable within the periods of time under consideration. Considering that even the inherent selfprotection of unshielded packages decreases with time and further progress in mining engineering must be presumed, the final classification of the material as irrecoverable will not be possible from the perspective of the safeguards authority, but this evaluation must rather be coupled to technological developments in mining engineering. This must be particularly considered in the light of high proliferation potential which the final repository represents for a state wishing to undertake a diversion.

I.e. in the case of undiluted conditioning of the final disposal products it cannot be expected that the material will finally be released from safeguards with respect to the two emplacement alternatives which can be taken into consideration (tunnel emplacement with lost shielding or borehole emplacement without lost shielding). The prerequisites for applying Article 35 VA are however fulfilled for both types of emplacement, namely that the recovery of nuclear material . . . is currently not possible nor desirable . . . In this case it is envisaged that the Agency and the Community should consult each other about the application of suitable safeguards. A statement on what the IAEA could regard as suitable safeguards is purely speculative at this point in time since there is no applicable experience. A process of intensive discussions with and between the safeguards authorities is necessary to elucidate this problem.

Emplacement in such a manner that the material remains accessible for verification would, apart from the technical feasibility, not fulfill the essential objectives of the final repository concept, namely isolating the material from the biosphere and possibilities of further human access. Accessible emplacement under ground would probably raise so many problems for reasons of heat dissipation and rock stability that this could no longer be regarded as a modification of the reference concept but would rather require a new concept to be compiled.

Under these assumptions the advantages of underground storage in comparison to storage above ground do not become immediately apparent. From the safeguards aspect storage above ground would undoubtedly be preferable since e.g. a diversion by simulated accidents blocking the entrance can be ruled out.

By way of summary it can be said that realistic possibilities of ensuring the safeguardability of the final repository according to current safeguards practice by modifying the reference concept cannot be envisaged at this time. Nevertheless, Art. 35 VA could represent a starting point for the discussion of a safeguards agreement deviating from current safeguards practice. Strictly speaking, the preceding considerations are only valid for the case of spent light-water reactor nuclear fuel. For fuels from special types of reactors, the criteria of Art. 11 of the VA could possibly make a termination of safeguards conceivable due to the different conditions in this case with respect to burn-up of the fuel, its dilution or the lack of an industrially applicable reprocessing procedure.

## 5.4 Possibilities of a Solution in the Institutional Sector

The starting point for institutional solutions is the fact that in order to implement a diversion, apart from the necessary technical measures, a considerable degree of organizational work must be undertaken. In the organizational sector additional barriers could be set up by multinational forms of cooperation which would impede the organizational implementation of a diversion and increase the risk of detection. A further aspect is possibly that the extension of international interconnections would increase vulnerability of the states to sanctions.

In the case of a final repository in an EURATOM member state, the logical consequence of the proprietary conditions is first of all considering the inclusion of EURATOM in the management and operation of the repository. The establishment of a direct final repository under the sole national control of a EURATOM state would presume that the Community had renounced its proprietary rights to the emplaced material. In view of the long-term proliferation aspects of the final repository, EURATOM's renunciation of proprietary rights and thus possible associated extended safeguards does not appear compatible with the objectives of the Community.

Pursuant to Art. 77 of the EURATOM Treaty, the Community undertakes to ensure that the nuclear materials are not employed for any purposes other than those envisaged. By final renunciation of its proprietary rights the Community would relinquish its otherwise derivable extended possibilities of codetermination and safeguards and would thus curtail its safeguards function. The final disposal of EURATOM material under the sole national control of a member state must therefore be classified as difficult to reconcile with the spirit of the EURATOM Treaty. It must also be examined whether it is desirable from a national point of view to operate a direct final repository under exclusive national control since a much greater obligation towards the international community can result from having to invalidate suspicious factors which could be interpreted as diversion attempts.

A conceivable alternative solution would be that a member state could implement final disposal on behalf of the Community, whereby Community conditions would have to be observed. This variant would correspond most closely to the interests of the Federal Republic of Germany. The Community's proprietary and safeguards reservations would thus be ensured and internationally verifiable. This model can also be evaluated as advantageous from the aspect of national acceptance.

The model with the highest institutional proliferation barrier would involve implementation of final disposal by the Community itself as a multinational undertaking where the member state would make available territory and infrastructure. Final disposal could thus ensue analogously to the deposition of nuclear material envisaged in Art. 80 of the EURATOM Treaty. However, from a national point of view this model raises significant acceptance problems since it implies the possibility of the final disposal of foreign material from EURATOM states. In view of the geographical and political situation of the Federal Republic of Germany it remains to be examined whether the extensive loss of sovereignty on the part of the host nation associated with this solution would be desirable.

The INFCE Conference provided essential impulses for considering institutional aspects and this is reflected in the IPS working group. It must, however, be remembered that institutional aspects are regarded by the IAEA as complementary, i.e. supplementary, measures and not as alternatives to stringent technical safeguards.

Due to the associated proliferation barrier, institutional models with multinational codetermination or cooperation undoubtedly represent an approach to the general NP problems of a final repository. However, they are not appropriate for solving the safeguards problem. In the first instance, institutionalization within the multinational EURATOM framework must be considered for a direct final repository in the EURATOM area as a consequence of the conditions of the EURATOM Treaty. From the point of view of the IAEA, this is hardly a drastic change in comparison to the current situation since the EURATOM area is already characterized by multinational safeguards. For the IAEA, institutional models would therefore have to go beyond the EURATOM framework and involve a form of international cooperation. Apart from the questions of the extent to which international cooperation can be implemented for a direct final repository and whether this is acceptable to the host country, the specific safeguards problem will not be solved by an international cooperation model either. Institutional models can thus be ruled out in the foreseeable future as an approach to solving the safeguards problems of a direct final repository.

# 6 CONCLUSIONS

The development of an internationally acceptable safeguards concept for the direct final repository raises a large number of problems which require intensive discussion with the safeguards authorities and which cannot be clarified a priori with the current state of the art.

| Final Disposal Phase | Safeguards Effectiveness Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| Phase 1: Transport above ground, leaving the conditioning facility - beginning shaft transport | acceptable | | |
| Phase 2: Transport below ground, beginning shaft transport - backfilling on site | acceptable since FDP's still accessible | | |
| Phase 3: Storage during the operational period, backfilling the FDP's - sealing the geological repository (backfilling the shafts) | unsolved problems | | |
| Phase 4: post-operational phase, after backfilling the shafts | unsolved problems | | |

**Table 6-1: Safeguards Effectiveness During the Various Operational Phases of the Final Repository**

As far as the effectiveness of safeguards possible at the present state of the art is concerned during the various operational phases of the final repository (Table 6-1), then the following can be ascertained: sufficient safeguards can be ensured both during the phase of transport above ground (Phase 1) as well as in the phase of underground transport of the final disposal packages until they are backfilled on site (Phase 2).

During the operational phase, the safeguards on the already emplaced final disposal packages (Phase 3) can consist of permanent design verification, although problems can be recognized in evaluating their effectiveness. The same is true of verifying the integrity of the shutdown repository in the post-operational phase (Phase 4).

An initial approach to solving the safeguards problem of a final repository (cf. Table 6-2) was envisaged in a modification of the existing IAEA safeguards philosophy. The IAEA would accordingly have to accept a safeguards model based essentially, or in the post-operational phase exclusively, on C/S measures. Since in this case the probability of detection, i.e. the essential parameter of IAEA safeguards, cannot be quantified at the present state of development, such an approach would be classified as unacceptable by the IAEA. If anomalies occur, e.g. in the case of a false alarm, the nuclear material cannot be verified.

Even a second approach envisaging the further technical development of safeguards elements cannot provide any basic solution to these inherent safeguards problems for the same reasons.

A third approach consists in modifying the reference concept, for example by dissolving and diluting the fuel, to ensure the safeguardability of the final repository according to current safeguards practice. No realistic possibilities are in sight in this case either, since this would cast doubt upon many of the desired characteristics of a direct final repository.

| Approach | Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| Alterations to the existing IAEA safeguards philosophy | IAEA would have to accept purely a C/S safeguards concept | | |
| | | | + intensive permanent facility safeguards |
| | ——— currently no solution ——— | | |
| Further and possibly redevelopment of safeguards elements | no basic solution to the safeguards problem | | |
| Adaptation of the reference concept to valid safeguards practice | —— no realistic possibility in sight —— | | |
| Institutional approaches | additional proliferation barrier but not a solution to the safeguards problems | | |

**Table 6-2: Assessment of the Solutional Approaches**

Institutional models with multinational codetermination or co-operation (fourth approach) undoubtedly represent a simplification of the NP problems in the final repository due to their associated proliferation barriers. Apart from the resulting questions of political acceptance they are not appropriate for solving the safeguards problem either. In this context, the establishment of a direct final repository must pay special attention to the role of EURATOM resulting from its proprietary and safeguards functions.

Before a final resolution, it is interesting to compare the essential NP aspects of direct final disposal with reprocessing. Table 6-3 shows this comparison with respect to differences in the fields of facility technology, safeguards technology and NP policy. This brief summary makes the advantages for a backend strategy with reprocessing quite clear.

On the basis of the facts and analyses compiled here the conclusion becomes obvious that a back-end strategy with direct final disposal is problematical from a safeguards aspect since doubt must be cast upon the technical realization of a safeguards concept.

For certain types of fuel element where reprocessing is not envisaged nor economical, Art. 35 of the VA can provide a possible solution. In the case of the limited emplacement of spent fuel elements, international safeguards could be negotiated pursuant to this Article.

| Reprocessing | Direct Final Disposal |
|---|---|
| **Technical Characteristics:** | ● Plutonium Determination |
| Pu determination after fuel dissolution, precision $\pm$ 1-2%; comparison with burn-up computations (destructive assay) | Pu determination planned by fuel element monitor, precision $\cong \pm 5\%$ (non-destructive assay) |
| | ● Whereabouts of the Plutonium |
| Pu separation by processing into MOX fuel elements | accumulation of Pu in underground final repository ("plutonium mine") |
| use of Pu in nuclear reactors | access to Pu increasingly easier due to decay of the fission products |
| | ● Technology |
| sensitive RP technology required, export control through international agreements | conventionally available mining technology |
| **Safeguards:** | ● Measures |
| Pu and U accountancy by analytical methods; complementary: near real time accountancy, possibly containment/surveillance | item counting (operational phase)<br>containment/surveillance (after backfilling the tunnels) |
| | ● Evaluation |
| quantifiable IAEA guidelines with back-up measures | no back-up solution in the case of anomalies |
| **NP Policy:** | |
| Storage of excess separated Pu can be realized within a future IPS system | worldwide application of direct final disposal on the basis of long-term perspectives (social and political stability) undesirable |
| in the EURATOM area unrestricted utilization and consumption right | in the EURATOM area, politically undesirable consequences on the basis of proprietary rights to the nuclear material |

**Table 6-3: NP Aspects of Direct Final Disposal in Comparison to Reprocessing**

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# 8 LIST OF ABBREVIATIONS

| | |
|---|---|
| AVR | Arbeitsgemeinschaft Versuchsreaktor GmbH |
| AWM | Alternative Waste Management |
| BHF | Bulk Handling Facility |
| C/S, CS | Containment/Surveillance |
| DBE | Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe (German Society for the Construction and Operation of Final Repositories for Waste Material) |
| DSB | Dry Storage Bin |
| DSP | Dry Storage Package |
| EURATOM | European Atomic Energy Community |
| FA | Facility Attachment |
| FDC | Final Disposal Canister |
| FDP | Final Disposal Package |
| FE | Fuel Element |
| HAW | Highly Active Waste |
| HC | Hot Cell |
| HM | Heavy Metal |
| IAEA | International Atomic Energy Agency |
| INFCE | International Nuclear Fuel Cycle Evaluation |
| IPS | International Plutonium Storage |
| ISFM | International Spent Fuel Management |
| KFA | Kernforschungsanlage Jülich GmbH (Jülich Nuclear Research Centre) |
| KfK | Kernforschungszentrum Karlsruhe (Karlsruhe Nuclear Research Centre) |
| KMP | Key Measurement Point |
| LS | Lost Shielding |
| LWR | Light Water Reactor |
| MBA | Material Balancing Area |
| MWd | Megawatt Day |

| | |
|---|---|
| NDA | Non-Destructive Assay |
| NMI | Nuclear Material Index |
| NP Treaty | Non-Proliferation Treaty |
| PAE | Projekt Andere Entsorgungstechniken (Alternative Waste Management Project) |
| PWR | Pressurized Water Reactor |
| RP | Reprocessing |
| SIR | Safeguards Implementation Report |
| SP | Strategic Point |
| SQ | Significant Quantity |
| THTR | Thorium High-Temperature Reactor |
| TUG | Programmgruppe Technik und Gesellschaft (Programme Group Technology and Society) |
| VA | Verification Agreement |
| VACOSS | Variable Coding Seal System |
| WSQ | Weighted Significant Quantity |

# 9 LIST OF TABLES

# 10 LIST OF FIGURES